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Optimising beverages for satiety: the role of sensory characteristics, expectations and nutrient content

Keri McCrickerd

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University of Sussex

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Declaration

The thesis conforms to an ‘article format’. The first chapter presents an overview of the field and the research undertaken, and the final chapter presents the conclusions and a discussion. The middle chapters consist of discrete papers written in a style that is appropriate for publication.

The following papers from this thesis have been published, or are under review, in full in peer-reviewed journals:

Paper one as:

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Paper two as:

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McCrickerd, K., Chambers, L. & Yeomans, M.R. (2014). Fluid or fuel? Context of consumption is important for the satiety value of a beverage. *PLoS ONE*, 9(6).

The author contributions for all of the papers presented in this thesis are clearly acknowledged at the end of each paper. All of the work presented in this thesis was supported by a Studentship awarded by the BBSRC DRINC initiative.

I hereby declare that this thesis has not been and will not be, submitted in whole or in part to another University for the award of any other degree.

Signature:

Keri McCrickerd

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UNIVERSITY OF SUSSEX

KERI MCCRICKERD

DPhil EXPERIMENTAL PSYCHOLOGY

**OPTIMISING BEVERAGES FOR SATIETY: THE ROLE OF SENSORY
CHARACTERISTICS, EXPECTATIONS AND NUTRIENT CONTENT****SUMMARY**

Regularly consuming caloric beverages has been linked to obesity and weight gain and evidence suggests this is because beverages have a weak impact on satiety responses (behavioural and physiological). Using a series of experimental studies this thesis explored the cognitive and sensory features of caloric beverages that might enhance the anticipated and actual satiating power of their nutrients.

Paper one characterised the sensory characteristics associated with expectations of hunger, fullness and thirst, finding that food and beverage products anticipated to be creamier and thicker were expected to be more satiating and less thirst-quenching. Paper two established that people can perceive subtle changes in beverage viscosity and manipulating thick and creamy textural cues strongly influenced the expectation that a beverage would be filling and suppress hunger after consumption. This was extended in paper three, which reported evidence suggesting that a sensorially enhanced beverage is selected and consumed in smaller portions.

Papers four and five investigated the satiating power of a caloric beverage consumed with satiety-relevant cognitive and sensory information. Paper four reported tentative evidence that a labelled satiety message influenced the satiating effect of caloric beverages when combined with thick and creamy sensory cues. Participants in Paper five reported greater satiety responses to a covert manipulation of beverage energy when consumed as a 'snack' rather than a drink. However, consuming the same beverage in a subtly thicker sensory context (without extra information) generated the largest satiety response to the different nutrient loads, perhaps because textural characteristics are the most reliable cue for nutrients.

Overall these studies suggest that caloric beverages may generate weak satiety responses because their nutrient-generated effects are not expected. Encouraging people to consider caloric beverages as a snack, or adding in nutrient-relevant sensory characteristics, may both help consumers regulate energy intake when consuming these products.

Contents page

1. Overview	1
1.1 Energy-containing beverages and weight gain	1
1.1.1 Overview outline	3
1.2 An overview of appetite and intake regulation.....	4
1.2.1 A Modified ‘Satiety Cascade’ Framework	5
1.2.1.1 Early cognitive and sensory influences.....	7
1.2.1.2 Post-ingestive and post-absorptive influences	8
1.2.1.3 Integrating early and later influences on satiety and Dietary Learning	10
1.2.1.4 External influences on satiation and satiety	12
1.2.1.5 Considering individual differences	13
1.2.2 Summary: An integrated approach to satiation and satiety.....	14
1.3 Targeting the satiating power of beverages	16
1.3.1 What is the evidence that beverages have a weak impact on satiety?	16
1.3.2 Physical and sensory characteristics	17
1.3.2.1 Food form and viscosity.....	17
1.3.2.2 The Sensory experience	19
1.3.2.3 Learning about the satiating effects of a beverage	21
1.3.2.4. Sensory-nutrient effects on satiety	24
1.3.1.4 Summary	26
1.3.2 Cognitions and consumption.....	26
1.3.2.1 Expectations of satiation and satiety	26
1.3.2.2 Product labelling	29
1.3.2.3 Context of consumption.....	32
1.3.3 Summary	34
1.4 Optimising the satiating power of a beverage: research aims and outline.....	35
1.4.1 Paper one: Exploring the sensory basis of satiety and thirst expectations across a range food and beverage products.....	36
1.4.2 Paper two: Subtle changes in the flavour and texture of a drink enhance expectations of satiety	36

1.4.3 Paper three: Does modifying the thick texture and creamy flavour of a drink change portion size selection and intake?	37
1.4.4 Paper four: Can satiety-relevant labelling improve the anticipated and actual satiating effect of a high-energy beverage with enhanced sensory characteristics?38	
1.4.5 Paper five summary: Fluid or fuel? The context of consuming a beverage is important for satiety.	38
2. Paper one	40
2.1 Abstract	41
2.2 Introduction.....	42
2.3 Method	44
2.3.1 Participants	44
2.3.2 Design	44
2.3.3 Food and beverage product stimuli	44
2.3.4 Appetite ratings	45
2.3.5 Anticipated sensory characteristics and Expectations of fullness, hunger and thirst	46
2.3.6 Procedure.....	46
2.3.7 Analysis.....	47
2.4 Results	49
2.4.1 Expectations of satiation and thirst across the different food products	49
2.4.2 Exploring the relationships between sensory and nutrient characteristics of the products and expected impact on appetite.....	50
2.4.3 Building regression models.....	52
2.4.4 Predictors of expected fullness immediately and hunger +1	53
2.4.5 Predictors of expected thirst immediately and one hour later.....	54
2.4.6 The role of cross-participant appetite, BMI and eating style	56
2.5 Discussion	58
2.5.1 Acknowledgements	62
2.5.2 Authors contributions.....	62
Appendix 2.1.....	63
Appendix 2.2.....	67

3. Paper two	68
3.1 Abstract	69
3.2 Introduction.....	70
3.3 Method: Study one.....	73
3.3.1 Participants.....	73
3.3.2 Fruit drinks	73
3.3.3 Measures	74
3.3.3.1 Viscosity	74
3.3.3.2 Sensory ratings.....	74
3.3.4 Procedure.....	75
3.3.5 Data Analysis	76
3.4 Results: Study one	77
3.4.1 Viscosity.....	77
3.4.2 Sensory evaluations of the test drinks	77
3.4.3 Relating sensory characteristics to viscosity.....	78
3.4.4 Summary	78
3.5 Method: Study two	80
3.5.1 Participants.....	80
3.5.2 Test drinks.....	80
3.5.3 Measures	81
3.5.3.1 Hunger, fullness and thirst	81
3.5.3.2 Sensory evaluations and filling rating.....	82
3.5.3.3 Expected satiety	82
3.5.4 Procedure.....	83
3.5.5 Data analysis	83
3.6 Results: Study two	85
3.6.1 Filling ratings	85
3.6.2 Expected satiety	85
3.6.3 Relating the filling rating to expected satiety	87
3.6.4 Sensory and hedonic evaluations of the drinks	87
3.6.5 Hunger, fullness and thirst pre- and post- test.....	88
3.6.6 Summary	88
3.7 Discussion	89

3.7.1 Conclusion	92
3.7.3 Acknowledgements	92
3.7.4 Authors contributions	93
4. Paper three.....	94
4.1 Abstract	95
4.2 Introduction.....	96
4.3 Method	99
4.3.1 Participants	99
4.3.2 Design	99
4.3.3 Standard breakfast	99
4.3.4 Test drinks	100
4.3.5 Subjective appetite	102
4.3.6 Sensory and hedonic evaluations of the drinks	102
4.3.7 Procedure.....	102
4.3.8 Data analysis	103
4.4 Results	105
4.4.1 Total intake.....	105
4.4.2 Total left in the glass	106
4.4.3 Changes in rated appetite	107
4.4.4 Sensory and hedonic ratings of the drinks	109
4.4.5 Participant feedback	109
4.5 Discussion	111
4.5.1 Conclusion	113
4.5.2 Abbreviations	113
4.5.3 Author contributions	114
5. Paper four	115
5.1 Abstract	116
5.2 Introduction.....	117
5.3 Method	120
5.3.1 Participants	120
5.3.2 Design	120

5.3.3 Test drinks	121
5.3.4 Labels	122
5.3.5 Food diary and recording pack.....	123
5.3.6 Diary coding.....	125
5.3.7 Procedure.....	126
5.3.8 Data Analysis	127
5.4. Results	129
5.4.1 Expected ‘fillingness’	129
5.4.2 Time until first eating episode	132
5.4.3 Size of first eating episode	132
5.4.4 Total energy intake over the test days.....	132
5.4.5 Percentage compensation for the additional nutrients in the HE drink.....	133
5.4.6 Changes in rated appetite pre- to post-beverage	135
5.4.7 Sensory and hedonic ratings of the test drinks.....	136
5.4.8 Debrief questions	136
5.5 Discussion	138
5.5.1 Author contributions	141
Appendix 5.1.....	142
6. Paper five	154
6.1 Abstract	155
6.2 Introduction.....	156
6.3 Materials and Methods	159
6.3.1 Ethics statement	159
6.3.2 Design	159
6.3.3 Participants.....	159
6.3.4 Test foods and drink.....	160
6.3.5 Beverage context.....	162
6.3.6 Procedure.....	163
6.3.6 Debrief questionnaire	165
6.3.7 Data analysis	166
6.4 Results	168
6.4.1 Lunch intake.....	168

6.4.2 Changes in rating appetite	169
6.4.3 Water-intake	170
6.4.4 Sensory ratings of the test products	172
6.4.5 Debriefing questionnaire	174
6.5 Discussion	176
6.5.1 Author Contributions	180
7 General discussion	181
7.1 Conclusions.....	181
7.1.1 Are beverages expected to be less satiating than other food forms?.....	181
7.1.2 Are the sensory characteristics of caloric beverages limiting their anticipated satiating power, and can they be enhanced to increase expectations of satiety and impact behaviour?	183
7.1.3. Can satiety-relevant cognitive and sensory cues influence the satiating effect of nutrients consumed as a beverage?	185
7.2 Implications	187
7.3 Wider discussion points.....	188
7.3.1 Possible mechanisms.....	189
7.3.2 Thirst	192
7.3.3 Limitations	192
7.3.3.1 Methodological considerations	192
7.3.3.2 Alcohol and caffeine	194
7.3.3.3 Participants.....	196
7.4 Future direction	197
7.5 Final conclusion	200
8. References	201

1. Overview

The problem of obesity is worldwide and it was recently estimated that by the year 2030, 2.16 billion people across the globe will be overweight and 1.12 billion obese (Popkin, Adair, & Ng, 2012). According to the World Health Organisation (2008) global obesity levels doubled between 1980-2008, a time period coinciding with shifts in the way many people eat, drink and move around in their daily lives. For many individuals obesity reflects energy imbalance resulting from overconsumption relative to energetic need, encouraged by western and westernised food environments, where palatable, highly processed and pre-prepared energy rich foods, are highly accessible, widely advertised and often cheap to buy. Beyond the immediate impact of obesity on an individual's health and quality of life, countries with some of the highest obesity rates (e.g. USA, Mexico and UK) have begun to realise the significant environmental, social, political and economic implications of an obese nation. This requires researchers to investigate the features of the current food environment and dietary behaviours that can be targeted to improve energy regulation.

1.1 Energy-containing beverages and weight gain

It is unlikely that there is one specific dietary component causing excessive energy intake, but the regular consumption of caloric beverages has been highlighted as one particular contributor to positive energy balance and weight gain (Kaiser, Shikany, Keating, & Allison, 2013). The beverage industry is huge and growing, with the two largest beverage companies, The Coca-Cola Company and Pepsico Inc., reaching record global sales in the last 10 years (Kleiman, Ng, & Popkin, 2012). Products include carbonated soft drinks, ready-to-drink tea and coffee products, flavoured waters, fruit and vegetable juices, isotonic 'sports' drinks, energy drinks, functional drinks and dairy based beverages. Sales of flagship full-energy brands Coca-Cola and Pepsi have taken a dip in recent years as consumers begin to replace these with low-calorie 'diet' equivalents (Kleiman *et al.*, 2012), such as Diet Coke and Pepsi Max, in response to government initiatives aimed at reducing energy consumption from these beverages. Nevertheless, people are still consuming a significant amount of calories in liquid form, such that beverages now contribute to a large proportion of our daily energy intake (Bleich, Wang, Wang, & Gortmaker, 2009; Kant, Graubard, & Atchison, 2009; Ng,

Mhurchu, Jebb, & Popkin, 2012): in the UK nearly one fifth of an adult's daily energy intake is provided by nutritive beverages, primarily in the form of carbohydrate (Ng *et al.*, 2012). For example, a large proportion of both the hot and cold beverages available in the café chain STARBUCKS ® (including non-coffee based products) contain between 300-600 kcal per serving. The increasing proportion of energy consumed as beverages is worrying as it has been suggested that the regular consumption of beverages may uniquely promote excessive energy intake because energy consumed in liquid form has a particularly weak effect on appetite and intake regulation (discussed in detail in section 1.2.1).

So, is energy consumed as a beverage linked to weight gain and will reducing beverage consumption promote weight loss? Several review papers point to a positive association between the consumption of caloric beverages and increased energy intake and body weight (Drewnowski & Bellisle, 2007; Malik, Schulze, & Hu, 2006; Vartanian, Schwartz, & Brownell, 2007), cardiovascular disease and Type 2 diabetes (Hu & Malik, 2010). However, a large proportion of this data was from epidemiologic cross-sectional association studies, across a mix of children, adolescents and adult participants, so in addition to methodological heterogeneity, causal links (independent of other food choices, lifestyle, health and socio-economic factors) between self-reported sole consumption of caloric beverages and the development of overweight and obesity cannot be inferred from these data (see: Drewnowski & Bellisle, 2007; Vartanian *et al.*, 2007). The strongest and most reliable evidence for the role of caloric beverage consumption in overweight and obesity comes from randomised control trial (RCT) interventions assessing the effect of consuming caloric beverage on changes in body weight overtime.

Kaiser, Shikany, Keating and Allison (2013) conducted the most recent meta-analyses of randomised control trials investigating the effect of both adding and reducing what they termed nutritively sweetened beverages (NSB) to/from the diet, building on an earlier meta-analysis conducted by the same group (Mattes, Shikany, Kaiser, & Allison, 2011). The researchers concluded that evidence from seven interventions where NSBs were *added* to a person's diet (evidence was from both adults and children) showed a reasonably strong effect of the beverages on increased BMI over the intervention period (3-52 weeks intervention depending on the study). Eight

interventions assessing the effects of *reducing* NSB intake on body weight over periods of 4-78 weeks (depending on the study) were also identified. Five studies replaced NSBs with lower energy drinks in the treatment groups, and in the remaining three studies the treatment groups were simply discouraged from drinking caloric beverages. The meta analysis revealed negligible effects on changes in BMI overall, although the researchers did highlight a small reduction in the rate of weight gain for those persons who were overweight pre-intervention, an effect also reported in their previous paper (Mattes *et al.*, 2011). This, however, contrasts with a more recent intervention reporting that obese women who consumed 1 litre/day of a sugar sweetened beverage gained a similar (and small) amount of weight over a four week period relative to obese women who consumed 1 litre/day of no-calorie artificially sweetened version of the same beverage (Reid, Hammersley, Duffy, & Ballantyne, 2014).

The evidence presented by Kaiser *et al.* (2013) suggests that regular consumption of NSBs could be an important contributing factor to excessive energy intake, but that the *weight gain* resulting from increasing beverage consumption is not necessarily mirrored by a similar magnitude of *weight loss* when these beverages are removed from the diet. This is likely to reflect people compensating for their habitual beverage intake by consuming other caloric foods and suggests that removing caloric beverages from the diet may not always be appropriate for weight management if they are simply replaced.

1.1.1 Overview outline

Considering the popularity of caloric beverages, the impact they have on weight gain, and the ineffectiveness of simply removing these calories from the diet on weight management, an alternative approach to the problem of caloric beverages is to consider the properties of the beverages themselves that could be changed, in order to strengthen the impact of the nutrients they contain on appetite regulation. This is the focus of the research presented in this thesis. The next two sections of this overview outline key processes in short term human energy regulation (section 1.2), and then considers what it is about caloric beverages specifically that might limit their impact on the appetite system and ultimately whether these features can be improved for better energy regulation (section 1.3).

1.2 An overview of appetite and intake regulation

Probably the most important step in identifying how the nutrients we consume influence the expression of appetite and excess energy intake is acknowledging the complexity of energy intake regulation and eating behaviour. The following section aims to briefly conceptualise the factors influencing energy intake regulation, but first it is useful to define some of the terms as used in this thesis.

Appetite: in the context of food intake regulation appetite refers to a general desire or urge to consume food (Yeomans & Bertenshaw, 2008), but more specifically a person's qualitative experience of food intake (Blundell *et al.*, 2010), characterised in this thesis by reported feelings of hunger, fullness, thirst and desire to eat. Measuring these states can be problematic given that they depend on introspection and an individual's interpretation of sensations, which may or may not be physical, such as sensations of 'stretch', 'weight' and 'fullness' in the stomach (physical) or experiencing a clear liking for a food (psychological).

Satiation: refers to the collection of events ultimately leading to the termination of a meal and outside of this thesis satiation has also been referred to as within-meal satiety (Blundell *et al.*, 2010). Factors that affect satiation will influence meal size.

Satiety: is characterised by the suppression of hunger, sustained feelings of fullness and ultimately the inhibition of further eating post-ingestion, arising from all the processes involved in the digestion of nutrients and their metabolic effects.

Caloric beverages: this is a general term for what are described in the literature as sugar-sweetened and nutritively-sweetened beverages, often referring to the following energy-containing beverages: carbonated and non-carbonated soft-drinks, fruit juices, dairy-based drinks and isotonic sports drinks. In the context of this thesis 'caloric beverages' does not refer to alcoholic or caffeinated products. Considering the potential psychopharmacological effects of alcohol and caffeine, the effect of these beverages on appetite regulation has often been considered separately in the literature. However, the particular attraction of these beverages and their potential impact on energy intake regulation is briefly discussed in section 7.2.3.2.

1.2.1 A Modified ‘Satiety Cascade’ Framework

The Satiety Cascade is an influential framework used to conceptualise the psychobiological systems affecting food intake regulation, first described by Blundell, Rogers and Hill (1987) and later by Blundell and colleagues (Blundell, 1991; Blundell *et al.*, 2010; Mela, 2006). This framework outlines the processes that influence the ability of an eating episode to generate *satiation* and *satiety*. A modified version of the original Satiety Cascade is presented in Figure 1.1. Representing short-term eating behaviour as in this framework, exposes the clear cyclical link between the psychological and physiological processes (e.g. beliefs and expectations, sensory experience, gastrointestinal responses and circulating hormones) underlying the behavioural and experiential aspects of food selection and intake from one meal to the next (e.g. hunger and fullness sensations, meal size, the time a person waits until the next meal, the size of the next meal etc.).

Studies measuring the development of satiation tend to focus on *ad libitum* consumption of a test food(s), measured in weight or energy content, and changes in rated appetite from pre- to post-meal. On the other hand, satiety is characterised by the suppression of hunger and subsequent energy intake and the most common way of measuring the satiety value of a food is through serving it in a fixed portion (a ‘preload’), and measuring one or more of the following: subsequent changes in rated appetite sensations; gastrointestinal motility and hormone profiles; the time taken until the next meal; the size and composition of the next meal; total daily energy intake (typically measured using a food diary). Given the multifaceted nature of eating behaviour, accurate measures of satiation and satiety attempt to control or measure the different environmental, cognitive, sensory and physiological influences (whether intentionally manipulated or not) on meal termination and subsequent appetite and intake. The following subsections (1.2.1.1 – 1.2.1.5) briefly outline the key processes to consider in short term energy intake regulation.

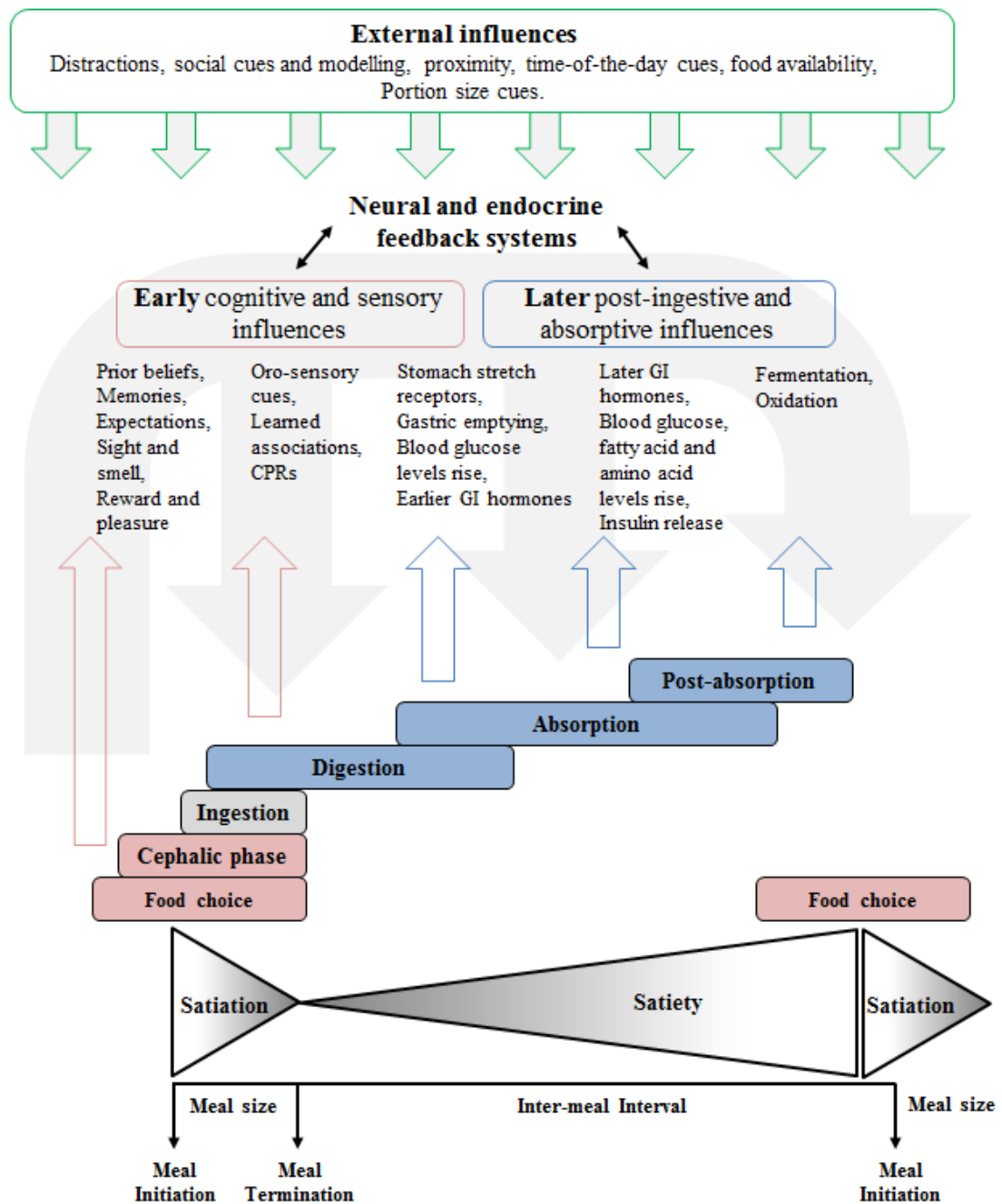


Figure 1.1 A Modified Satiety Cascade framework, adapted from Blundell, Hill and Rogers (1987), Mela (2006) and Smeets, Erkner and de Graaf (2010), illustrates the integration of cognitive, sensory and post-ingestive influences on satiety and satiety, characterised by changes in appetite, actual food intake (quality, quantity and timing) and physiological responses and further dependent on characteristics of the environment, the individual and the composition of the food. **CPRs**: Cephalic Phase Responses; **GI**: Gastrointestinal.

1.2.1.1 Early cognitive and sensory influences

As Figure 1.1 illustrates, food choice and intake are regulated by a variety of metabolic, cognitive and sensory processes. The temporal aspect of the Modified Satiety Cascade Framework suggests that satiation and the initial development of satiety is largely influenced by prior beliefs, expectations and a food's sensory characteristics. Both adults and children can estimate how filling a food will be before it is consumed (Brunstrom, Shakeshaft, & Scott-Samuel, 2008; Brunstrom & Shakeshaft, 2009; Pilgrim & Kamen, 1963). Such beliefs can also be generated by a food's perceived volume (Brunstrom, Collingwood, & Rogers, 2010a), its sensory characteristics (Hogenkamp, Stafleu, Mars, Brunstrom, & de Graaf, 2011; McCrickerd, Chambers, Brunstrom, & Yeomans, 2012), product labelling (Chambers, Ells, & Yeomans, 2013; Fay, Hinton, Rogers, & Brunstrom, 2011b) and contextual cues from the food environment (Capaldi, Owens, & Privitera, 2006).

So do these sorts of expectations impact intake regulation? Beliefs about the consequences of consuming a food are thought to be an important determinant of food selection and consumption (Wilkinson *et al.*, 2012) and can influence how much food we select and consume, the experience of satiation and satiety post-consumption (Brunstrom, Brown, Hinton, Rogers, & Fay, 2011) and even the physiological response to nutrient ingestion (Crum, Corbin, Brownell, & Salovey, 2011). These type of expectations are associated with a person's familiarity with the food (Brunstrom, Shakeshaft, & Alexander, 2010b; Brunstrom *et al.*, 2008; Hardman, McCrickerd, & Brunstrom, 2011) and whether it has previously been consumed to fullness (Ferriday, Rogers, Fay, Shakeshaft, & Brunstrom, 2011; Irvine, Brunstrom, Gee, & Rogers, 2013), suggesting that a person's experience with a food can modify these beliefs.

However, the visual evaluation of food can trigger more than satiety-relevant beliefs. Just the thought of food is enough to elicit salivation (Wooley & Wooley, 1973), gastric acid secretion (Feldman & Richardson, 1986) and some gastrointestinal hormone release (Rodin, 1985; Smeets *et al.*, 2010; Wynne, Stanley, McGowan, & Bloom, 2005): a conditioned response to food-related stimuli, termed Cephalic Phase Responses (CPRs). When food enters the oral and olfactory cavity these CRPs continue to prepare the body for the optimal digestion and absorption of ingested nutrients: oro-sensory stimulation activates the vagus nerve which initiates subsequent gustatory and

endocrine responses, such as gastric and intestinal secretions (hydrochloric acid, gastrin, lipases and digestive enzymes from the pancreas and duodenum) and further release of earlier gastrointestinal hormones such as pancreatic polypeptide, insulin and ghrelin, a peptide hormone produced primarily in the stomach and proximal small intestine (see Smeets *et al.*, 2010 for a recent review). The cephalic phase ghrelin response, for example, is thought to be a physiological driver of hunger and desire to eat (Cummings, 2006; Cummings *et al.*, 2001; Wren *et al.*, 2001), meal anticipation (Crum *et al.*, 2011; Drazen, Vahl, D'Alessio, Seeley, & Woods, 2006), initiation (Cummings, Frayo, Marmonier, Aubert, & Chapelot, 2004) and increased food intake (Wren *et al.*, 2001).

1.2.1.2 Post-ingestive and post-absorptive influences

Once consumed, a food enters the stomach, which is densely innervated and both chemically and mechanically equipped for ingestion (Berthoud & Powley, 1992; Camilleri, 2006; Horowitz & Dent, 1991). During ingestion gastric distension can be a potent physiological satiation signal. Geliebter *et al* (1988) demonstrated that participants ate less during a meal and reported feeling more full and less hungry when they were fitted with a gastric balloon inflated to a volume of at least 400 ml. Subsequent research showed that the ingestion of food had a similar effect: Cecil, Francis and Reed (1998) found that an intragastric infusion of soup decreased rated appetite whereas an intraduodenal infusion of the same soup did not, and gastric volume created by real food has been positively linked to sensations of fullness (Goetze *et al.*, 2007). However, the ability of gastric distension to reduce food intake and hunger sensations was increased when combined with nutrient delivery to the duodenum (Castiglione, Read, & French, 1998; Oesch, Ruegg, Fischer, Degen, & Beglinger, 2006), which also reduced discomfort reported by gastric distention alone, in favour of feelings of fullness (Feinle, Grundy, & Read, 1997). Together, this indicates that gastric distension alone is not sufficient for satiation and satiety.

Indeed, the physiological response to ingested foods continues all the way down the gastrointestinal tract. Negative feedback from mechanoreceptors responding to the arrival of nutrients in the small intestine slows gastric emptying and gastrointestinal transit time (Edelbroek *et al.*, 1994), affecting the time that a food is in contact with digestive enzymes. The chemosensory detection of nutrients throughout the intestinal tract impacts intake regulation. Peptide hormones such as ghrelin, pancreatic

polypeptide and insulin (mentioned in 1.2.1.1.), as well as CCK (Cholecystokinin), gastrin, GLP-1 (Glucagon-like Peptide-1), PYY (Pancreatic Peptide YY) and GIP (glucose-dependent insulintropic peptide), are all released at different levels of the gastrointestinal tract (from ingestion to digestion and absorption) in response to the presence of nutrients. Studies of humans and other animals have attempted to elucidate the role of these gastrointestinal hormones in intake regulation, and this has been the subject of several recent and in-depth reviews (see: Cummings & Overduin, 2007; Delzenne *et al.*, 2010; Wynne *et al.*, 2005). CCK, for example, is rapidly released into circulation primarily from the duodenum and jejunum in response to the delivery of nutrients from the stomach, particularly digestive products of fat and protein (Liddle, Goldfine, Rosen, Taplitz, & Williams, 1985). CCK acts to increase gall bladder contractions, influencing the release of digestive enzymes (Beglinger, 1994; Liddle *et al.*, 1985; Liddle, Morita, Conrad, & Williams, 1986; Moran & Schwartz, 1994; Muurahainen, Kissileff, Derogatis, & Pi-Sunyer, 1988), and inhibition of gastric emptying, which is thought to enhance satiation by increasing or maintaining gastric volume and suppressing further intake (Kissileff, Carretta, Geliebter, & Pi-Sunyer, 2003; Muurahainen, Kissileff, Lachaussee, & Pi-Sunyer, 1991).

A discussion of each of the appetite-related hormones identified so far is beyond the scope of this thesis. However, it is important to note that while often studied separately, the roles of gastrointestinal hormones in intake regulation are unlikely to be independent. For example, in a state of low adiposity, reduced longer-term adiposity signals to the brain (leptin and insulin) can limit the intake-suppressing action of CCK (Havel, 2001). Furthermore, the combined administration of PYY with GLP-1 (Neary *et al.*, 2005), but not PYY and PP (Neary *et al.*, 2008), were reported to reduce subsequent appetite and intake when the same doses administered alone did not. Thus, some gastrointestinal hormones appear to act synergistically to influence satiety and appetite regulation whilst others may not.

Post-absorptive nutrient effects on satiety primarily occur through detection and metabolism of the products of digestion, such as glucose, free fatty acids and amino acids that have been absorbed into the bloodstream. For example, an increase in fatty acid oxidation in the liver is associated with enhanced satiety (Gatta *et al.*, 2009), particularly the more rapidly oxidised of medium- and short-chain fatty acids (SCFA)

which may have a greater impact on diet-induced thermogenesis and enhance sensations of fullness and hunger (Kamphuis, Mela, & Westerterp-Plantenga, 2003; Westerterp-Plantenga, Rolland, Wilson, & Westerterp, 1999), although not always (Raben, Agerholm-Larsen, Flint, Holst, & Astrup, 2003b). Fermentation in the colon is another post-ingestive process proposed to influence satiety. Some dietary fibres and resistant starches are unaffected by digestive processes until they reach the colon, where the action of bacteria can break them down into SCFAs, such as butyric, propionic and acetic acid, and gases like carbon dioxide and methane and hydrogen (Hijova & Chmelarova, 2007; Wong, de Souza, Kendall, Emam, & Jenkins, 2006). It has been suggested that the SCFAs generated in the fermentation process influence the action of gastrointestinal peptides such as PYY, GLP-1 and CCK (Slavin, Savarino, Paredes-Diaz, & Fotopoulos, 2009; Sleeth, Thompson, Ford, Zac-Varghese, & Frost, 2010), and this is one potential explanation for the satiating effect of high-fibre foods (Fiszman & Varela, 2013; Karalus *et al.*, 2012). It should be noted, however, that the rate and SCFA production is dependent on the type and amount of both the microflora present in the colon and the carbohydrate source (Wong *et al.*, 2006), so the effects of fermentation on satiety are also likely to be dependent of these variables and different across individuals.

1.2.1.3 Integrating early and later influences on satiety and Dietary Learning

Although satiation and satiety can be defined separately the processes underlying these constructs form an overlapping and interacting cascade of responses to food and ingestion, a feature of food intake regulation that is illustrated in Figure 1.1. Cognitive and sensory signals generated by the sight and oro-sensory experience of food, and the post-ingestive and post-absorptive physiological signals generated by ingestion and digestion of nutrients, are combined and fed back through the peripheral nervous system and brain centres (mediated further by longer term metabolic signals). Together these signals generate the experience of satiation and satiety, such that no one factor is solely responsible for the satiating effect of a particular food. Cecil, Francis and Reed (1998) provided some clear behavioural evidence for this integration. The researchers demonstrated that 425 ml of soup infused into the duodenum did not impact rated hunger, fullness and desire to eat over a two-hour period, whereas rated appetite was reduced when the same soup was intragastrically infused, so as not to bypass the stomach, and appetite was suppressed further if the participants were told the infusion

was food compared to when they were told it was not. However, the soup was experienced as most satiating when it was consumed orally. This indicates that the satiating power of a food was most efficient when the post-ingestive effects generated at all levels of the gastrointestinal tract were experienced alongside the belief and sensory experience of consumption.

Dietary learning is the process that gives meaning to early cognitive and sensory cues generated by a food. Associative learning theories postulate that animals (including humans) form associations between the early experience of a food's sensory characteristics and the ingestion of nutrients, increasing preference for a novel food that is repeatedly associated with a positive post-ingestive experience compared to ones that have not been (Flavour-Consequence Learning: for a review of associative learning theories see Gibson & Brunstrom, 2007; Sclafani, 1997; Yeomans, 2006). In addition to learning to like caloric foods, animals also learn to estimate the post-ingestive satiating effects of its nutrients from its taste, odour and texture. Because the full post-ingestive effect of a food is generally not experienced until after consumption, these estimations can be used to efficiently adjust meal size and achieve an appropriate level of satiation and satiety (Le Magnen, 1955). This has been termed Learned Satiation and Learned Satiety (Booth, 1972; Booth & Davis, 1973; Booth & McAleavey, 1976) there have been several studies reporting that humans can learn to adjust meal-size in response to the repeated experience of consuming an energy dense (initially) novel target food, both by adjusting *ad libitum* intake of that target food (Learned Satiation) or by making compensatory adjustments to a later meal in response to a fixed portion of the target food (Learned Satiety) (Birch & Deysher, 1985; Booth, Mather, & Fuller, 1982; Booth & McAleavey, 1976; Hogenkamp, Stafleu, Mars, & de Graaf, 2012c; Louissylvestre *et al.*, 1989; Mars, Hogenkamp, Gosses, Stafleu, & De Graaf, 2009; Yeomans, Gould, Leitch, & Mobini, 2009; Yeomans, McCrickerd, Brunstrom, & Chambers, 2014; Yeomans, Weinberg, & James, 2005), although similar repeated exposure studies have failed to find these dietary adjustments (Brunstrom, 2005; Gibson & Brunstrom, 2007; Specter *et al.*, 1998; van Wymelbeke, Béridot-Thérond, de La Guéronnière, & Fantino, 2004; Zandstra, Stubenitsky, De Graaf, & Mela, 2002). Some researchers have questioned whether learned satiation and satiety can be separated from learned preferences through flavour-nutrient learning (Yeomans, 2012; Yeomans *et al.*, 2009; Yeomans *et al.*, 2005).

Perhaps the clearest evidence that humans learn to anticipate a gastric challenge is the presence of Cephalic Phase Responses before and during the initial stages of ingestion (see section 1.2.1.1). Our ability to make explicit judgements about the potential satiating effect of a food is likely to be another expression of this learning (Blundell *et al.*, 2010; Brunstrom, 2007), both of which are important contributors to satiation and satiety (see section 1.3.3).

1.2.1.4 External influences on satiation and satiety

The Satiety Cascade Framework describes the combination of psychological and physiological factors involved in intake regulation, but what is less clear is the relative importance of these processes in the complex environments many people live in today. Whilst blood glucose levels are tightly regulated, with fluctuating and rapid declines in level correlated with meal initiation (de Graaf, Blom, Smeets, Stafleu, & Hendriks, 2004; Delzenne *et al.*, 2010; Melanson, Westerterp-Plantenga, Campfield, & Saris, 1999), people do not necessarily consume food in response to energetic ‘need’ (Mela, 2006). Food price, availability and proximity (Wansink, 2004), time-of-the-day cues and social facilitation, such as the presence of friends eating (Herman, Roth, & Polivy, 2003), can all influence what an individual consumes and when. Distractions like watching TV (Bellisle, Dalix, & Slama, 2004; Bellissimo, Pencharz, Thomas, & Anderson, 2007; Blass *et al.*, 2006), playing computer games (Lyons, Tate, & Ward, 2013), listening to music (Stroebele & de Castro, 2006) and socially interacting with friends (Hetherington, Anderson, Norton, & Newson, 2006) all increase the amount of food a person consumes and limit the extent to which a person attends to the process of eating and internal cues for satiation and satiety (Hetherington *et al.*, 2006; Higgs & Donohoe, 2011; Mitchell & Brunstrom, 2005; Ogden *et al.*, 2013). Thus, distracting features of the environment also affect the amount a person consumes at subsequent eating occasions (Robinson *et al.*, 2013), potentially because attending to the features of a food can enhance food memories and a stronger memory for recent eating reduces future intake (Higgs & Donohoe, 2011; Higgs & Jones, 2013; Higgs, Williamson, & Attwood, 2008).

Other more subtle features of the food environment can affect what and how much we eat. People generally eat everything that is on their plate, something that has been

acknowledged in experimental studies but also appears to be characteristic of real-world eating behaviour (de Graaf *et al.*, 2005; Fay *et al.*, 2011a; Pilgrim & Kamen, 1963; Wilkinson *et al.*, 2012), at least in many Western countries: 90% of people asked in a UK survey reported that they always plan the amount of food that they are going to eat, and 92% of people reported that they always consume everything on their plate (Fay *et al.*, 2011a). Consequently, when people received larger portions of food or drinks, they tend to consume more than when they started with a smaller portion size (Rolls, Morris, & Roe, 2002; Rolls, Roe, & Meengs, 2010; Wansink & Kim, 2005; Wansink, Painter, & North, 2005a). This is particularly relevant when we buy and consume ready-to-eat foods from pre-prepared packets and get served a set portion in restaurants and cafes: in these instances how much we eat may depend on how much we start with (Rolls, 2003; Wansink, 1996). In a clever study, Wansink and Cheney (2005) served soup to participants, who could eat as much or as little as they liked. For half the participants the soup bowl covertly re-filled as they were eating and these participants ended up eating 73% more than those whose bowl did not refill. Interestingly, all participants thought they had consumed a similar amount, presumably one that conformed to the amount they perceived had been eaten from the bowl.

1.2.1.5 Considering individual differences

Although humans share common psychobiological mechanisms for energy intake regulation, such as those outlined in Figure 1.1, some individuals gain weight and even become obese over time, while others stay lean. This highlights the variability in energy intake regulation occurring across individuals. These differences may be biological, lending themselves to behavioural risk factors that are in turn influenced by features of the environmental, such as some of those identified above in 1.2.1.4. For example, individuals who were less able to detect oral fat reported a higher preference for and intake of high fat foods (Martínez-Ruiz, López-Díaz, Wall-Medrano, Jiménez-Castro, & Angulo, 2014; Stewart *et al.*, 2010; Stewart, Newman, & Keast, 2011) and in an environment where high-fat foods are readily available, a preference for fatty foods is likely to promote energy intake. Indeed, habitual consumption of a high-fat diet has been linked to increased body weight (Blundell *et al.*, 2005; Macdiarmid, Cade, & Blundell, 1996; Stewart *et al.*, 2011). However, some consumers of a high-fat diet appear to be more susceptible to weight gain than others (Blundell *et al.*, 2005; Macdiarmid *et al.*, 1996). *Susceptible* people showed a weak suppression of hunger in

response to a high-fat meal, retained pre-meal preference for high-fat foods when satiated, and more strongly enjoyed the taste of foods and eating larger portions compared to *resistant* consumers who maintained healthy body weight (Blundell & Finlayson, 2004; Blundell *et al.*, 2005). Thus, individuals will vary in their appetite-related responses to the same food stimuli.

Individual differences in constructs such as food enjoyment, responsiveness to food cues, satiety responsiveness and dispositions towards impulsivity and inhibition of further eating (see French, Epstein, Jeffery, Blundell, & Wardle, 2012 for a recent review of these constructs in relation to energy intake) have been conceptualised in a variety of independent measures. For example, the Three Factor Eating Questionnaire (TFEQ; Stunkard & Messick, 1985) was developed to conceptualise individuals differing in their reported tendency to restrict food intake (dietary restraint), to overeat (dietary disinhibition) and respond to sensations of hunger. The Children's Eating behaviour Questionnaire (CEBQ) was developed as a measure of constructs such as satiety responsiveness and food enjoyment in children (Carnell & Wardle, 2007; Wardle, Guthrie, Sanderson, & Rapoport, 2001). Measures such as the TFEQ have linked differences in disinhibition to an individual's satiety responses to ingested nutrients (Chambers & Yeomans, 2011; French *et al.*, 2012; Lee *et al.*, 2013) and body composition (Bryant, Kiezebrink, King, & Blundell, 2010), and differences in restraint to a person's ability to learn about the satiating effect of a novel food (Brunstrom & Mitchell, 2007; Yeomans, 2010b, 2012). A review of the different measures aimed at characterising individual differences in eating behaviours is not appropriate for this overview and is not a focus of this thesis, but as French *et al.* (2012) point out, research is still only beginning to explore the possible overlap and interaction between the independently developed constructs. It will be important, therefore, that additional research is conducted to refine the variety of individual differences in eating behaviour and examine how they interact with the food environment, and for researchers to consider these differences in the interpretation of their research findings.

1.2.2 Summary: An integrated approach to satiation and satiety

Section 1.2 briefly outlined the physiological, psychological and environmental factors involved in food intake regulation (summarised in Figure 1.1). Ultimately, a person begins to eat in response to a number of internal and external influences that do not

necessarily depend on energetic need. Before, during and after a food is consumed, a cascade of cognitive, sensory, gastrointestinal and metabolic signals promote sensations of satiety and influence food intake in the short term. Rather than working in isolation these processes overlap and interact and may be modulated further by longer-term adiposity signals and dietary learning. At any given time the internal physiological control of satiation and satiety can be moderated and even superseded by a variety of psychological and environmental influences. Importantly, the way in which the body responds to the ingestion of nutrients is an integrated process, depending on the characteristics of the food (such as sensory characteristics and nutrient profile), the person consuming it, their beliefs and expectations and the environment that surrounds them. Attempting to improve the satiating power of a beverage will need to consider all of these factors.

1.3 Targeting the satiating power of beverages

The research outlined at the beginning of Section 1.1 linked the consumption of nutritive beverages to weight gain and highlighted the need to consider how the properties of these types of beverages might be limiting the impact of these nutrients on appetite regulation. Section 1.2 then highlighted the multifaceted nature of appetite regulation, emphasising that a combination of environmental, cognitive, sensory, physiological factors and dietary learning will be important for the effective development of satiety. This section (1.3) presents the evidence that caloric beverages have a weak impact on satiety responses, discusses the possible reasons for this (in the context of energy-intake regulation) and the potential ways in which a beverages satiating power may be improved.

1.3.1 What is the evidence that beverages have a weak impact on satiety?

Short-term experimental evidence has reported that nutrients consumed as a beverage add to the total energy content of a meal rather than being incorporated into it (DellaValle, Roe, & Rolls, 2005; Panahi, El Khoury, Luhovyy, Goff, & Anderson, 2013; Rolls, Kim, & Fedoroff, 1990b), and that fluid calories consumed between eating occasions have a weaker suppressing effect on appetite sensations and future energy intake (DiMeglio & Mattes, 2000; Leidy, Apolzan, Mattes, & Campbell, 2010). A few studies have also reported no difference between the satiating effect of different food forms (Almiron-Roig, Chen, & Drewnowski, 2003; Almiron-Roig, Flores, & Drewnowski, 2004; Chapelot & Payen, 2010). However, in these studies researchers compared the effects of beverages like cola to a cookie, a ‘shake’ to a cereal bar or a liquid yogurt to a chocolate bar, and while these forms were generally consumed in equi-caloric portions, other features (such as volume, carbonation, flavours, palatability, cognitive appraisal and in many cases macronutrient composition, including fibre content) were not well matched. All of these factors could affect the satiating effects of the different liquid and solid items independent of food-form, and ultimately limit the conclusions that can be drawn from these studies.

The best evidence that nutrients consumed as a beverage have particularly weak satiating power come from studies which have attempted to change the form of the nutrients (solid vs. liquid) whilst maintaining the other features of the foods that might

affect satiety. These studies have consistently reported that beverages fail to suppress appetite and inhibit future energy intake in the same way as solid and semi-solid versions of the same foods (Cassady, Considine, & Mattes, 2012; Hulshof, Degraaf, & Weststrate, 1993; Mattes, 2005; Mattes & Campbell, 2009; Mourao, Bressan, Campbell, & Mattes, 2007; Tournier & Louis-Sylvestre, 1991). For example, Flood-Obbagy and Rolls (2009) investigated the impact of apple slices vs. apple sauce (the slices blended together) vs. pressed apple juice (with and with-out added pectin to match for fibre content) on subsequent food intake. The apple preloads were matched for energy, nutrient, and energy density, but the apple juice failed to reduce subsequent energy intake to the same extent as the puree and solid fruit versions. This effect was consistent regardless of the primary nutrient being consumed (Mourao *et al.*, 2007). This highlights consistent evidence for the weak satiating effect of nutrients consumed as a beverage.

So what features of beverages limit their satiating power and can these features be improved? The following two sections (1.3.2 and 1.3.3) consider in turn the physical features of a liquid that may be contributing to the reduced satiety value of drinks and the idea that cognitive/psychological factors might play a particularly important role in this.

1.3.2 Physical and sensory characteristics

1.3.2.1 Food form and viscosity

The evidence that a beverage is less satiating than the same nutrients consumed as a solid or semi-solid food suggests that the physical form of these nutrients influences their satiating effect. Evidence from animal studies reported that rats fed on a low-viscosity dietary supplement ate more and gained more weight than rats fed on a high-viscosity but nutritionally identical supplement (Davidson & Swithers, 2004, 2005), suggesting that the higher viscosity supplement was more satiating. In humans, a viscous beverage containing either guar gum or oat β -glucan suppressed appetite more than less-viscous beverages without these additional fibres (Lyly *et al.*, 2009), but the satiating effect of added fibres was reduced when they had been enzymatically treated to be low-viscosity (Lyly *et al.*, 2010). This is consistent with other research suggesting that viscous beverages are more satiating than less viscous versions with the same

energy content (Marciani *et al.*, 2000; Mattes & Rothacker, 2001; Perrigue, Carter, Roberts, & Drewnowski, 2010; Solah *et al.*, 2010; Zijlstra *et al.*, 2009b).

Contrasting evidence, however, has reported that a lower-viscosity liquid was experienced as more satiating than a viscous version (Clegg, Ranawana, Shafat, & Henry, 2012; Juvonen *et al.*, 2009; Peracchi *et al.*, 2000; Santangelo, Peracchi, Conte, Fraquelli, & Porrini, 1998). More contradictory still, studies have reported that higher-viscosity foods elicit both a slower (Juvonen *et al.*, 2009; Zhu, Hsu, & Hollis, 2013) and more rapid (Clegg *et al.*, 2012; Peracchi *et al.*, 2000; Santangelo *et al.*, 1998; Shimoyama *et al.*, 2007) gastric emptying rates compared to lower-viscosity versions, and also a reduction (Juvonen *et al.*, 2009; Peracchi *et al.*, 2000; Santangelo *et al.*, 1998) and no change (Zijlstra *et al.*, 2009b) in gastrointestinal hormone release after consuming a higher-viscosity food compared to a less viscous version. Thus, it is unclear from this research why low-viscosity beverages have a particularly weak influence on behavioural measures of appetite regulation.

These discrepancies, however, may represent inconsistent methodologies. The viscosity manipulations varied across studies, with many adding polysaccharide thickeners to manipulate viscosity (Juvonen *et al.*, 2009; Lyly *et al.*, 2009; Lyly *et al.*, 2010; Marciani *et al.*, 2000; Mattes & Rothacker, 2001; Perrigue *et al.*, 2010; Shimoyama *et al.*, 2007; Solah *et al.*, 2010; Zhu *et al.*, 2013; Zijlstra *et al.*, 2009b) and others simply processing foods to be smoother (Clegg *et al.*, 2012; Peracchi *et al.*, 2000; Santangelo *et al.*, 1998). The type and quantity of thickener used to manipulate viscosity differed considerably: locus bean gum, cellulose, alginate, pectin, modified starch and carrageenan were all used in quantities varying from 0.25 to 17.5g per serving consumed. Dietary fibres, which includes the water soluble ionic and non-ionic polysaccharides used in these studies, vary dramatically in their physiochemical properties which will affect how they change the viscosity and texture of a food or drink (depending on the food's water content, nutrients and temperature, for example), but also their ability to add bulk to foods, increase gastric volume, respond to changes in pH throughout the gastrointestinal tract, and ferment once in the colon (Fizman & Varela, 2013; Wanders *et al.*, 2013). All of these characteristics could lead to different post-ingestive effects and satiety profiles when consumed (section 1.2).

Another possibility is that inconsistencies in research outcomes occur because viscosity influences satiety through an earlier oro-sensory mechanism rather than a later post-ingestive one. The viscosity of a meal pre-ingestion is not necessarily directly related to gastric and intestinal viscosity (Hoad *et al.*, 2004) and dilution from secretions in the stomach and small intestine make it very difficult to predict changes in viscosity throughout the digestive tract (Dikeman & Fahey, 2006; Dikeman, Murphy, & Fahey, 2006; Marciani *et al.*, 2000). Therefore it could be the oral experience of viscosity that is important for satiety. However, it is difficult to conclude that it is the oral experience of viscosity that is important for satiety, because the sensory characteristics of the test foods, such as their rheological and perceived sensory profiles, were generally not reported in the research presented in this section. This makes it hard to determine whether the textural differences between higher- and lower-viscosity test products were a) rheologically meaningful, b) perceivable and c) palatable. However, the four studies that did report the sensory evaluation of the test foods consistently found that the more viscous product was perceived to be thicker and experienced as more satiating, with the largest differences in appetite seen immediately (Zhu *et al.*, 2013; Zijlstra *et al.*, 2009b) and within the first 15 minutes after consumption (Mattes & Rothacker, 2001; Perrigue *et al.*, 2010; Zhu *et al.*, 2013). This suggests the oral experience of viscosity could be particularly important for the satiating power of liquids.

The following section investigates in more detail the role of oro-sensory experience and textural differences in food intake regulation, as a potential mechanism by which nutritive beverages generate a weak satiating effect.

1.3.2.2 The Sensory experience

It is clear that the sensory experience of a beverage is quite different to other food forms. Liquids are consumed at a much faster rate than solid and semi-solid foods (van Dongen, Kok, & de Graaf, 2011; Zijlstra, Mars, de Wijk, Westerberp-Plantenga, & de Graaf, 2008). For example, in one study it took participants on average 17 minutes to consume 500g of apples but just 1.5 minutes to drink 500g of apple juice (van Dongen *et al.*, 2011). Viscous, hard and chewy foods are often consumed more slowly and in smaller quantities than are less viscous and soft foods and drinks (Karl, Young, Rood, & Montain, 2013; Zhu *et al.*, 2013; Zijlstra, de Wijk, Mars, Stafleu, & de Graaf, 2009a;

Zijlstra *et al.*, 2008; Zijlstra *et al.*, 2009b; Zijlstra, Mars, Stafleu, & de Graaf, 2010) and when given the opportunity to eat as much as they like people consistently consume about 30% more of a liquid product compared to a thicker semisolid version of the same product (Hogenkamp, Mars, Stafleu, & de Graaf, 2012b; Zijlstra *et al.*, 2008; Zijlstra *et al.*, 2009b). It should be noted, however, that a solid food that is quicker to consume is not always consumed in a larger portion (Martin *et al.*, 2007; Zhu & Hollis, 2014). However, the fact that a liquid is *drank* and not *eaten* greatly reduces the time it takes to consume, particularly if using a straw. Hogenkamp and colleagues (2010) reported that consuming a beverage with a spoon compared to a straw increased the time the liquid was in the mouth and led to decreased intake. The researchers argued that people consumed more of the liquid because the limited oro-sensory exposure time it affords reduced its effect on satiety, but it is also likely simply that the faster speed at which the product was consumed with a straw compared to a spoon led to this difference in consumption.

It makes sense that a person will consume more apple juice *ad libitum* compared to apple slices simply because apple juice can be consumed faster, allowing more to be consumed before boredom or increased sensory satiety kicks in. But given that the oro-sensory experience of food contributes to the development of satiation, could limited oral exposure time also explain why a fixed amount of energy consumed as apple juice is less satiating in the time after consumption (i.e. has a reduced satiety value), compared to the same nutrients consumed as apple puree or as apple slices (see section 1.3.1)? Martens, Lemmens, Born and Westerterp-Plantenga (2012) tested this by standardising the rate of consuming both a solid and liquid version of peaches by asking participants to consume both food forms with cutlery, resulting in equal oral transit times. When consumed in this way the liquid (peaches blended in water) and the solid (peach segments eaten with a fork, plus water to drink) were equally satiating, eliciting similar effects on appetite and gastrointestinal peptide release. Indeed, eating slowly and taking pauses in-between bites to increase oral transit time is also associated with an increase in the gastrointestinal peptides PYY and GLP in response to the nutrients (Kokkinos *et al.*, 2010) and a suppression of the experience of hunger in the post-meal period (Andrade, Kresge, Teixeira, Baptista, & Melanson, 2012). Furthermore, varying oral stimulation by increasing the time a soup was held in the mouth during modified sham-feeding had a larger impact on suppressing appetite sensations and future intake

than increasing the actual gastric volume of a food achieved by intragastric infusion (Wijlens *et al.*, 2012). Thus, the weak sensory stimulation afforded by a beverage might limit their ability to generate satiety.

Liquids require little to no mastication and may fail to elicit cephalic-phase responses in the same way that solid foods that require chewing do (Teff, 2010; Teff, Devine, & Engelman, 1995). Increased chewing enhances oro-sensory exposure time and has been associated with decreased food intake and postprandial ghrelin concentration, and increased postprandial levels of CCK and GLP-1 (Li *et al.*, 2011). However, researchers have highlighted that while increased chewing and chewing effort can impact satiation (within meal), it is likely to have little impact on later appetite and food intake (Bolhuis *et al.*, 2014; Kong & Singh, 2008; Mattes & Considine, 2013). Furthermore, chewing gum failed to elicit some cephalic-phase preparatory responses (such as vagally mediated insulin and pancreatic polypeptide (PP) release) unlike chewing actual food (Teff, 2010). Thus, the mechanics of chewing alone may not be enough to elicit these responses, instead the meaning of the sensory experience may also be important: For example, chewing food is likely to be associated with nutrient delivery, whilst chewing gum provides little post-ingestive feedback rendering cephalic phase responding unnecessary. It is possible then, that the oro-sensory experience of a low-viscosity liquid is not sufficiently meaningful to influence similar preparatory cephalic-phase responses.

To summarise, beverages are consumed quickly, which limits their oro-sensory impact. Given the importance of the sensory experience for preparatory physiological responses and the development of satiety (see sections 1.2.1.1 and 1.2.1.3), the satiating power of caloric beverages may be greatly limited by their weak oro-sensory impact.

1.3.2.3 Learning about the satiating effects of a beverage

Section 1.2.1.3 highlighted that animals, including humans, can learn to estimate the satiating effects of a food by forming associations between its sensory characteristics and post-ingestive consequences. These estimations may be used to guide food choice and intake regulation. So why have we not learned about the potential satiating consequences of caloric beverages?

It is possible that the weak oro-sensory stimulation afforded by a caloric beverage (see 1.3.2.2) limits a person's ability to learn about the satiating effects of its nutrients. Mars *et al* (2009) investigated whether increasing the viscosity of a yogurt (and in turn increasing the oro-sensory signal) enhanced a person's ability to learn whether the yogurts novel flavour predicted its nutrient content. Participants consumed low and high-energy yogurts that were paired with one of two novel sweet flavours (either "rose apple" or "spice speculass"), with half of the participants receiving only high-viscosity yogurts, while the other half consumed only low viscosity yogurts. In the first two sessions the satiety value of a fixed portion of the high- and low-energy yogurts was assessed (indexed by changes in rated appetite over 90 minutes followed by test meal intake). Over the next 4 weeks participants consumed the high- and low-energy yogurts *ad libitum* for breakfast on 10 occasions for each version (20 exposures in total). After this learning period participants completed one more satiety-testing day for each yogurt. Results indicated that participants consumed the same amount (grams) of the high- and low-energy yogurts across all 10 exposures, when it had a low viscosity. On the other hand, participants consuming the high-viscosity yogurt tended to adjust their intake over the exposure period: reducing intake of the high-energy yogurt and increasing intake of the low-energy version. However, there was no difference in the satiating effect of a fixed portion of the yogurt from pre- to post-learning, regardless of the yogurt's energy content or viscosity. Furthermore participants in the high- and low-viscosity groups did not differ in their ability to recall the flavour paired with the high-energy yogurt, despite those consuming the high-viscosity yogurt reducing their *ad libitum* intake of these versions over the learning period.

These findings suggest that people are better at learning to adjust their intake of a higher-energy food when it is consumed in a viscous sensory context. However, this learning did not appear to be enough to enhance the satiety value of the product over time, and two later studies by the same group failed to find sensory-dependent effects of learning. One study found that participants' similarly reduced *ad libitum* intake of an equi-caloric liquid and semi-solid dairy product after three exposures to a fixed portion of the product (Hogenkamp *et al.*, 2012b) and another reported that after nine exposures to high-and low-energy liquid and semi-solid products, participants learned to increase subsequent lunch intake after the lower-energy version, but showed no adjustments after exposure to the higher-energy versions, and this was not affected by the product's

texture (Hogenkamp *et al.*, 2012c). Thus texture did not appear to enhance learning in these instances. Notably, however, participants did show some learned adjustment of food intake in both studies, indicating that it is possible to learn about the satiating value of liquids. Moreover, many of the human studies reporting dietary learning mentioned in section 1.2.1.3 used liquids to deliver novel flavour-nutrient pairings, providing further evidence that we can learn some information about the satiating effect of liquids, in a controlled laboratory setting at least.

An alternative consideration is that the ability to learn about the satiating effect of a beverage may be weakened if their sensory characteristics do not always predict nutrients (Davidson & Swithers, 2004). A high level of processing is used to create many popular beverage products and this may weaken the sensory-nutrient relationships they afford. Indeed, van Dogen, van de Berg, Vink, Kok and de Graff (2012) recently identified that common sensory-nutrient relationships, such as sweet taste associated with sugar content, and saltiness and savouriness associated with sodium and protein content, were weaker in more processed food items. This is interesting because the researchers only assessed these relationships in foods containing the target nutrients, so the sensory-nutrient relationships of many other processed foods and beverages (such as Diet Coke, which is sweet tasting but contains no sugar, and fat-free yogurt which is creamy but does not contain fat) may be weaker still. Over the last several decades, food manufacturers have exploited the creation of different artificial food additives to reduce the energy content of their foods, creating ‘diet’ products that maintain flavour and palatably. However, unlike lower-energy solid and semi-solid food products that generally require some nutrients for structure, a beverage’s high water content means they can be created nutrient free with sensory characteristics mimicking those of the ‘full calorie’ versions. For example, a person can consume a beverage containing artificial sweeteners and no nutrients (e.g. 330ml Coke Zero, 1 kcal and no sugar) that looks and tastes almost exactly the same as a version containing 35g of sugar (e.g. 330ml Coca Cola, 139kcal and 35g sugar).

Davidson, Swithers and colleagues reported that exposure to inconsistent sensory-nutrient relationships might impair the ability to learn about the satiating effects of a food (Davidson & Swithers, 2004; Swithers & Davidson, 2008; Swithers, Doerflinger, & Davidson, 2006): these studies showed that rats and mice exposed to artificially

sweetened foods (including liquids) that did not contain energy were less able to adjust their intake of other caloric sweet-tasting foods and compensate for this energy, which often led to weight gain. Similar learning studies have yet to be conducted in humans, but some preliminary research has suggested that self-reported habitual users of artificial sweeteners were less able to regulate energy intake in response to a high-energy sweetened beverage than low habitual consumers were (Appleton & Blundell, 2007), and showed weaker neuronal activation in the amygdala (an area associated with learning about the post-ingestive response of nutrients) to sucrose sweetened tastes (Rudenga & Small, 2012). There is, however, a large number of short and longer-term studies reporting that consuming artificially sweetened low-calorie foods and beverages in place of the full energy versions reduced or did not affect overall energy intake, both in short-term and longer-term trials (reviewed in Mattes & Popkin, 2009). More recently, participants advised to consume artificially sweetened low-calorie beverages over a 12-week period reportedly lost more weight than participants advised to drink water (Peters *et al.*, 2014). While it is unclear from this research whether exposure to inconsistent sensory-nutrient relationships in our diet poses a specific challenge to dietary learning and energy intake regulation in the short- and long-term, these findings do highlight the passive overconsumption of energy that can occur if intake is based on a beverage's sensory experience, rather than its energy content.

1.3.2.4. Sensory-nutrient effects on satiety

Several lines of evidence support the idea that the oro-sensory experience of drinking a low-viscosity caloric beverage limits its satiating power. Firstly, research presented in section 1.3.2.1 suggests that a more viscous beverage (created by the addition of soluble fibres) is experienced as more satiating and that this is probably due to enhanced oro-sensory stimulation rather than post-ingestive effects, as dilution in the stomach means that differences in oral viscosity are often not reflected in gastrointestinal viscosity. Secondly, the speed with which beverages are consumed reduces the oro-sensory exposure time it affords during consumption, which has been linked to diminished cephalic-phase preparatory responses and reduced satiety (see section 1.3.2.2). Finally, the sensory experience of low-viscosity caloric beverages may not be particularly predictive of the nutrients they contain. Together this suggests that enhancing the sensory characteristics of a caloric beverage to be more in-line with its energy content might improve its satiating power.

It has often been reported that protein is the most satiating macronutrient, with research concluding that foods containing a larger proportion of energy as protein are more satiating than equicaloric foods with a lower protein content (Hill & Blundell, 1987; Veldhorst *et al.*, 2008; Westerterp-Plantenga, Nieuwenhuizen, Tomé, Soenen, & Westerterp, 2009), although not always (Blatt, Roe, & Rolls, 2011; Degraaf, Hulshof, Weststrate, & Jas, 1992; Raben, Agerholm-Larsen, Flint, Holst, & Astrup, 2003a). Whilst investigating the satiating power of protein, Bertenshaw, Lluch, and Yeomans (2008) reported that a protein-rich beverage suppressed hunger and later energy intake more than an equicaloric carbohydrate-rich beverage, and the more protein added to a beverage the more satiating it was experienced to be (Bertenshaw, Lluch, & Yeomans, 2009). However, as the beverage's protein content increased so too did its perceived thick and creamy sensory characteristics, and in a subsequent study the researchers showed that the enhanced sensory experience may have contributed to the satiating power of protein in this context: when the sensory characteristics of a protein-rich and a carbohydrate-rich equi-caloric beverage were manipulated to taste similarly thick and creamy (by adding guar gum and dairy/creamy flavours), they were equally satiating (Bertenshaw, Lluch, & Yeomans, 2013). This suggests that the relatively high satiating effect of protein might in part depend on the textural and flavour profile, at least in a beverage context. A limitation, however, is that the researchers did not specify the quantities of guar gum used to match the thickness between beverages, so this outcome may be confounded by possible differences in the post-ingestive effect of the guar gum that may have contributed to the satiating effect of these beverages.

On the other hand, Yeomans and Chambers (2011) indicated that the satiating power of a sensory-enhanced product *depended* on its energy content: in that study participants consumed a high- (279 kcal) and low-energy (78 kcal) protein-rich beverage (sensorially matched) 30 minutes before a test lunch. Consequently, participants reported similar appetite sensations and consumed a similar amount at lunch after each beverage, despite consuming an additional 201 kcal in the higher-energy version. However, when the high- and low-energy beverages were made to taste thicker and creamier the higher-energy beverage, but not the lower-energy version, was more satiating with participants feeling less hungry and reducing lunch intake. Rather than having a general effect on satiety, this indicates that satiety-relevant sensory

characteristics *interact* with the energy value of the food delivered post-ingestion to influence satiety. This is in line with the satiety framework described in Figure 1.1 and in section 1.2 which proposes that the development of satiety occurs through a combination of early sensory cues and later post-ingestive nutrient effects, but suggests that the sensory input is most successful if it corresponds to the energetic value of the food that has been consumed, a finding that has been replicated in subsequent studies from this group (Chambers *et al.*, 2013; Yeomans *et al.*, 2014).

1.3.1.4 Summary

It is likely that the sensory characteristics of many low-viscosity beverages are not satiety-relevant and research indicates that enhancing textural and taste cues can improve the satiating power of a product if they are in-line with the nutrients that are delivered post-consumption. Perceived thick texture and creamy sensory additions might improve the satiating power of a beverage if they correctly signal the presence of energy before it is consumed.

1.3.2 Cognitions and consumption

As previously outlined, the experience of satiety depends on the integration of a range of environmental, cognitive, sensory, physiological and metabolic signals (see Figure 1.1). The previous section 1.3.1 explored the role of the physical characteristics of a beverage may play on the sensory and post-ingestive signals involved in satiation and satiety. But a beverage's fluid form contributes to more than just sensory experiences. Expectations and prior beliefs we hold about caloric beverages compared to 'foods' will influence their satiating power (see section 1.2.1.1 and Figure 1.1). The next section considers the role of expectations and other higher level or top-down cognitions on the satiating power of a beverage.

1.3.2.1 Expectations of satiation and satiety

As outlined in section 1.2.1.1 and 1.2.1.3, a potential consequence of learning is that people then hold explicit expectations about the satiating consequences of different foods, which can influence food choice and the development of satiety. It is possible that beverages may not be explicitly expected to be as satiating as other 'foods' (Mattes, 2005), but as yet this has not been explicitly tested.

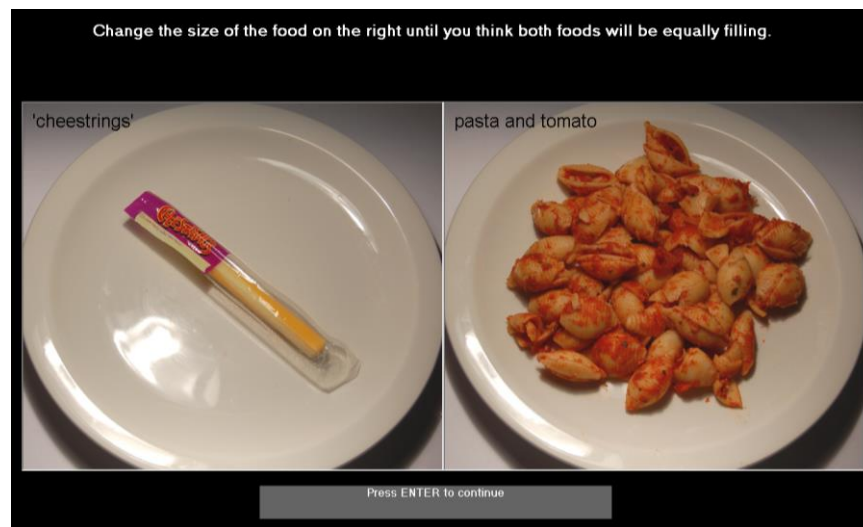


Figure 1.2 An *expected satiation* task used in Hardman, McCrickerd and Brunstrom (2011): participants select the portion of pasta and sauce (comparison food) they think would make them feel equally as full as the ‘cheese string’ (target food). The larger the portion of pasta sauce selected (kcal), the more satiating the target food is expected to be and *vice versa*.

Brunstrom and colleagues (Brunstrom *et al.*, 2008; Brunstrom & Shakeshaft, 2009) have developed a computerised task to quantify the expectations people hold about the satiating effect of foods (see Figure 1.2 for an example). This requires participants to indicate the anticipated satiating effect of a *target food* with a known energy content compared, calorie for calorie, to a *comparison food* (Brunstrom *et al.*, 2008; Brunstrom & Shakeshaft, 2009; Hardman *et al.*, 2011). In their studies both adults and children demonstrated that they were able to select how much of a familiar comparison food, such as pasta and tomato sauce, they thought they would need to eat to feel equally as full (*expected satiation*) and/or to suppress hunger to the same extent (*expected satiety*) as a known portion of a target food. As highlighted in section 1.2.1.1, expectations of satiation and satiety are thought to depend on our previous experience: foods that are rated as more familiar (Brunstrom *et al.*, 2010b; Brunstrom *et al.*, 2008; Hardman *et al.*, 2011) and/or have been previously consumed to fullness (Ferriday *et al.*, 2011; Irvine *et al.*, 2013), are expected to be more satiating. Brunstrom and colleagues argue this is because people have learned about the satiating effect of more familiar foods. However, controlled laboratory studies do not provide conclusive evidence that specific expectations about the satiety value of a food can be easily changed with repeated exposure (Hogenkamp, Brunstrom, Stafleu, Mars, & de Graaf, 2012a; Wilkinson &

Brunstrom, 2009; Yeomans *et al.*, 2014). Furthermore, in one study Irvine, Brunstrom, Gee and Rodgers (2013) measured the expected satiety value of a novel food, sushi, and although participants who were not familiar with this food judged it to be less satiating than those who were, they could still make a judgement. This suggests that expectations of satiety are based on more than product-specific familiarity, and perhaps there are more general features of a food that can drive these beliefs.

Emerging evidence indicates that the extent to which a food is expected to be satiating is linked to its physical characteristics. Commercially available dessert products (custards and yogurts) perceived to be thicker (Hogenkamp *et al.*, 2011) or heavier (Piqueras-Fiszman & Spence, 2012) were expected to be more filling than similar products that were less thick or heavy. Moreover, chewy and salty savoury foods were also expected to be more filling than less chewy and salty foods (Forde, van Kuijk, Thaler, de Graaf, & Martin, 2013). This suggests that if beverages are not expected to be particularly satiating, altering their sensory context to be more in-line with these cues that are associated with satiety could be an important way to enhance their anticipated satiating effect.

Is enhancing the anticipated satiating effect of a beverage likely to impact its actual satiating power post-consumption? Brunstrom *et al.* (2011) demonstrated that participants who expected a smoothie to be more satiating (because they believed it contained a large portion of fruit) experienced the smoothie as more filling over a 4 hour period post-consumption, compared to participants who believed the smoothie contained a small portion of fruit and expected it to be less filling. In a more elaborate study, researchers investigated the effect of expectations on satiety by successfully convincing participants that they would be consuming cherry-flavoured liquids and jellies that had the ability to either be solid or liquid in their stomach (Cassady *et al.*, 2012). The researchers achieved this by showing participants a video where the products were shown to either liquefy or solidify in the presence of pretend ‘gastric acid’. Participants consumed both the beverage and jelly on two occasions, once believing it would be liquid in the stomach and another time that it would be a solid. Consequently, both the sensory experience and the beliefs about their post-ingestive effects contributed to satiety responses: consuming the cherry liquid was associated with faster gastric emptying and gastrointestinal transit times, a smaller decline in

ghrelin and reduced insulin and GLP-1 release relative to consuming the oral-solid jellies. However, the beliefs about consumption most strongly influenced appetite sensations and later intake, with participants consuming less at a test meal four hours later and feeling less hungry and more full in this time than when they believed the product was solid rather than liquid in their stomach. There was also some evidence that expecting the product to be solid in the stomach slowed gastrointestinal transit times.

These findings, particularly those from Cassady *et al.* (2012), suggest that manipulating a person's beliefs about the effect a beverage will have on satiety-related sensations can enhance the actual experience of satiety and even physiological responses to nutrients, at least in the short term. However, for real-world beverage products food companies and governments cannot lie to consumers about the ingredients in a product or tell them it will turn to solid in their stomach when in reality it will not. Thus, more realistic ways of improving the anticipated satiating effect of a beverage need to be considered.

1.3.2.2 Product labelling

It is promising that the satiating effect of beverages might be improved by changing a person's beliefs about its satiating effect. One practical and popular way of changing beliefs about the foods and beverages we consume is through product labelling. Several studies have investigated the effect of low-fat labelling on food intake, with some finding that participants' satiety response depended on labelled fat content rather than the actual energy content, with a food labelled low-fat being less satiating than the same food labelled as high-fat (Caputo & Mattes, 1993; Shide & Rolls, 1995), although in another study the actual fat content rather than labelled information was more important for satiety (Yeomans, Lartamo, Procter, Lee, & Gray, 2001).

Simply labelling calorie information is another way to generate expectations that could influence eating behaviour. In an early study, Wooley, Wooley and Durnam (1972) investigated caloric anticipation on the satiating effect of high-and low-energy meal replacement beverages consumed over a week period. Participants were aware that the meal replacements they were consuming would be either high or low calorie but were unable to accurately guess which was which on each day. Instead, the participants reported the meal replacement being more satiating on the days that they *perceived* the

calorie content to be high, rather than when the actual caloric load was high. Two other studies have investigated the effect of labelled calorie content on satiety responses, finding that a food labelled “high calorie” suppressed appetite and future intake more than the same food labelled “low calorie”, with one study suggesting this was independent of the actual energy content (Wooley, 1972) while another reported that a high-calorie label only enhanced the satiating power of a lower-energy item (180 kcal), arguing that the nutrient effects of a high energy product (530 kcal) were too large to be influenced by beliefs (Hogenkamp *et al.*, 2013).

Although a realistic way to change beliefs about a product, a problem with labelled calorie information is determining what exactly consumers understand from this information; consumers generally consider high calorie and high fat foods to be a less healthy choice (Grunert, Fernandez-Celemin, Wills, Storcksdieck Genannt Bonsmann, & Nureeva, 2010; Wasowicz-Kirylo & Stysko-Kunkowska, 2011), but it is less clear whether ‘calories’ actually relate to the perception of satiety (i.e. suppression of appetite sensations) in the mind of a consumer. Current front-of-pack nutrition labelling guidelines in the UK (Food Standards Agency and Department of Health, 2013) promote a consistent labelling system to inform consumers of the caloric content (in kcal) and the proportion of fat, saturated-fat, sugar and salt (all in grams) contained in one serving of food and beverage products, with a colour coding system to identify whether these quantities are low (yellow), medium (amber) and high (red). Guidelines stipulate that this information should be presented in an accessible label on the front of the package, meaning that calorie content is generally available to consumers in the ‘real-world’. The problem is that the product manufacturers decide the portion size in which these are presented (they must always give kcal per 100g/ml too if the portion size is bigger/smaller than this). For many popular beverages, such as Coke, recommended serving sizes range from 150 ml to 375 ml, depending on the size of the can and bottle, which range from 150 ml to 2000 ml. More often than not the suggested serving size of caloric beverage is a lot smaller than the quantity provide in the bottle (e.g. in a 500 ml bottle of Coke the recommended portion size is 250 ml). In the best case scenario a person will be able to accurately measure out the specified portion and/or calculate specific quantities of calories for the food or portion of food they are consuming, and then comprehend what this means for their total energy intake if they eventually consume the whole serving. However, a study assessing the use of front-of-

pack calorie information found that less than 10 % of the 687 adults (all parents) were able to correctly estimate the caloric content of a beverage product when the serving size information was for less than the total quantity in the pack (Vanderlee, Goodman, Sae Yang, & Hammond, 2012), suggesting that if person was to serve themselves more than the recommended amount (assuming they could accurately do this) they would likely have little idea of how many calories their portion contained, despite the label.

In addition to calorie and nutritional labelling, which may not be clearly understood, product names, slogans and imagery are widely employed by the food and beverage industry to generate explicit beliefs about the potential consequences of consuming a product. Some labels and branding specifically aim to generate satiety-relevant expectations (e.g. Marks & Spencer's "Feel fuller for longer" range), and similar messages could be applied to beverages. However, the few studies investigating the effects of these sorts of labels on the actual satiety value of a food have shown mixed results. Chambers, Ells and Yeomans (2013) found that satiety-relevant product labelling ("Stay-full" vs "Lighten") had no effect on the actual satiating power of a high-protein beverage. On the other hand, Crum, Corbin, Brownell and Salovey (2011) reported that a chocolate milkshake labelled as "Indulgent" and as having a high calorie content, had a greater suppressing effect on the orexigenic hormone ghrelin compared to the same chocolate milkshake labelled as low calorie and a "Sensi-shake". Despite this there was no evidence that the labelling affected appetite sensations or later food intake.

It is possible that the mixed effect of satiety-relevant labelling on actual intake behaviour reflects an inconsistent interpretation of the different labels and messages. Moreover, people could simply not believe these labels in the first place (Brunstrom *et al.*, 2011; Chambers *et al.*, 2013). This seems plausible since more convincing methods of changing the expected satiating effect of a food (e.g. the belief that a liquid would gel in the stomach, section 1.3.2.1) had quite a strong impact on the subsequent experience of its satiety. Another possibility is that labelled information is ineffective if it contrasts with the other sensory and contextual cues from the food itself, which might explain why a creamy chocolate milkshake had a similar effect on appetite despite the "Indulgent" vs. "Sensi-shake" labelling, as in the study of Crum *et al.* (2011).

1.3.2.3 Context of consumption

Labels can be used to generate expectations of consuming a beverage, but perhaps a less obvious factor affecting what we think about a food is the context within which it is consumed. This could be a particularly important consideration for beverage consumption since beverages are often consumed a specific context, such as ‘drinks’ for thirst and keeping hydrated.

Research has indicated certain situational cues, such as eating without utensils, not sitting down at a table and consuming foods that are pre-prepared and pre-packaged can lead people to interpret consumption of the same foods as a ‘snack’ rather than a ‘meal’ (Wansink, Payne, & Shimizu, 2010), and this contextual information can influence the food’s actual satiating power. For example, a food that is perceived to be a snack was experienced as less satiating than the same food that is perceived to be a meal (Capaldi *et al.*, 2006). Pliner and Zec (2007) proposed that people hold meal-schemas that are based on contextual information associated with eating a meal (as noted in Figure 1.1, memories are an important part of our prior beliefs about foods). They reported that people who consumed a food in a context that was consistent with reported features of their ‘meal’ schemas (e.g. sitting down at a dining table with a table cloth and utensils) felt more full and ate less at a later meal compared to those people who consumed the same food in a less meal-relevant context (eating alone on a laboratory table with the foods presented as ‘samples’). Presumably, considering the eating occasion to be a meal implies that it will be satiating (because meals are generally eaten to ‘fill you up’), and this belief enhances the actual experience of satiety once the foods are consumed.

In a similar way, the context within which energy containing beverages are consumed could be limiting their satiating power. Firstly, a liquid consumed as a soup is more satiating than the same liquid consumed as a beverage: Mattes (2005) compared the satiating value of an apple beverage and apple soup, comprising the apple juice served hot in a bowl and consumed with a spoon. Both servings were similar in volume, nutrient and caloric content. The apple soup suppressed appetite more than the apple beverage in the time after consumption, and participants tended to consume less overall on the days the liquid was consumed as a soup, rather than a beverage. The only differences between the apple soup and apple beverage were that the soup was consumed 1) hot rather than cold and 2) out of a bowl with a spoon rather than drank

from a glass. Some evidence suggests the temperature of a food can influence gastric emptying in some populations of people (Mishima *et al.*, 2009), although contradictory findings have been previously reported (Brobeck, 1985) and other evidence suggests that consuming the same soup hot (60°C) or cold (1°C) did not affect its satiating power (Rolls, Fedoroff, Guthrie, & Laster, 1990a). Thus, the temperature difference between the soup and beverage in Mattes' study may not have had much impact on eating behaviour. Regarding consumption with a spoon, this feature of consuming a soup results in an eating rate similar to that of solid foods (van Dongen *et al.*, 2011) and one possibility is that soups are more satiating than drinks because they are consumed at a slower rate and have increased oro-sensory exposure (see section 1.3.1.2). But consuming a soup with a spoon might also provide satiety-relevant contextual information because utensils are part of a 'meal schema' and associated with food and eating (Pliner & Zec, 2007; Wansink *et al.*, 2010) while the act of drinking tends to be associated with thirst (Martens & Westerterp-Plantenga, 2012).

Studies reporting the effect of liquid meal-replacers on weight loss provide the second line of evidence that the context of consuming a beverage may be important for satiety. Randomised clinical trials indicate that drinking meal replacement "shakes" in the place of one meal a day can promote more weight loss than consuming a reduced energy diet plan (for a review, see: Heymsfield, van Mierlo, van der Knaap, Heo, & Frier, 2003; Keogh & Clifton, 2005). Sugar, in some instances high-fructose corn syrup, is the principal ingredient in many meal-replacement beverages, such as Slim-Fast® shakes, and often in a comparable amount to that found in caloric soft drinks (Drewnowski & Bellisle, 2007). However, a key difference between a meal-replacement beverage and a typical soft drink is that the former is consumed as a "food" in a meal context. While these trials do not specifically show that the weight-loss benefits of consuming meal-replacement beverages is down to an enhanced satiating power, they do indicate that consuming a beverage as a 'food' is a potentially important factor. However, there are two important points to note. Firstly, protein and small quantities of fibre may also been present in these beverages to enhance the sensory quality to be more 'shake'-like (for example, a Slim-Fast® vanilla shake is described as "sweet and creamy"), and as outlined in sections 1.3.1.3 and 1.3.1.4 these sensory cues could contribute to satiety by signalling nutrients. Secondly, the people taking part in trials of meal-replacement beverages were probably motivated to change their eating behaviours in order to lose

weight. But perhaps this is also just indicative of how important a person's mind-set is for the control of eating behaviour.

1.3.3 Summary

The research and ideas presented in this final section build on the principles of the satiety cascade framework presented at the start of this thesis, proposing that beyond the nutrients we actually consume, the satiating effect of a food or beverage is also dependent on higher level cognitive influences generated by the product, its packaging, the context within which it is consumed and a person's beliefs and interpretation of this. It is likely that the satiating power of a caloric beverage is limited by the fact that both the body and mind do not appropriately anticipate its energetic value. Beyond the physiological response to nutrients, a beverage's sensory context, contextual cues, and consumer beliefs and expectations could all be targeted to improve the satiating effect of nutrients consumed in these products.

1.4 Optimising the satiating power of a beverage: research aims and outline

Convincing evidence indicates that nutrients consumed as a beverage have a limited satiating power, which is considered to be the main reason why regularly consuming these products can contribute to weight gain. The evidence outlined in this overview highlights the multifaceted nature of satiety and appetite control in humans, particularly that the satiating value of foods is dependent on more than its nutrient value alone. The evidence outlined in sections 1.3.2 and 1.3.3 suggests that the satiating effect of a low-viscosity caloric beverage is limited by its fluid sensory characteristics, but also because these products may not be expected to be particularly satiating or considered to be ‘food’.

The overarching aim of this thesis is to better understand and to improve the satiating power of caloric beverages. The original research presented in papers one-five builds on the idea that the weak oro-sensory impact of low-viscosity energy-containing beverages are limiting their satiating value, not simply because of the mechanics of minimal oral processing, but because the sensory experience and the context within which they are consumed are not predictive of their energy content making it less likely to be ‘counted’ by the appetite system. These papers aimed to answer the following questions:

- 1.** Are beverages expected to be less satiating than other food forms?
- 2.** Are the sensory characteristics of caloric beverages limiting their anticipated satiating power, and can they be enhanced to increase expectations of satiety and influence behaviour?
- 3.** Can satiety-relevant cognitive and sensory cues influence the satiating effect of nutrients consumed as a beverage?

1.4.1 Paper one: Exploring the sensory basis of satiety and thirst expectations across a range food and beverage products

It has been suggested that caloric beverages have a weak impact on appetite regulation because they are not expected to be satiating, perhaps limited by a beverage's fluid characteristics. Paper one investigated the extent to which the anticipated sensory characteristics of ready-to-consume food and beverage products predict their expected effect on hunger, fullness and thirst, and whether beverages are expected to have a weaker satiating effect than other food forms. This paper also introduces the idea that in addition to expectations of hunger and fullness, the anticipated impact on thirst (which has not been measured before) may be an important expectation generated specifically by beverages. Using computer-based methodology, participants evaluated 40 widely available food and beverage products (varying in physical characteristics, packaging and actual nutrient content) for anticipated sensory characteristics, pleasantness, familiarity, and expected impact on appetite. Participants were asked to generate product-specific judgements of how full they expected to feel immediately after consumption (*fullness immediately*), expected feelings of hunger one hour later (*hunger +1*), and how thirsty they would feel both immediately (*thirst immediately*) and one hour after consumption (*thirst +1*). The extent to which these expectations were related to and predicted by the product's anticipated sensory and nutrient characteristics were explored.

1.4.2 Paper two: Subtle changes in the flavour and texture of a drink enhance expectations of satiety

Evidence suggests that viscosity (thicker texture/mouthful) and creaminess (both texture and flavour) are sensory characteristics that are associated with nutrients and that consuming beverages is instead associated with thirst-reduction. The two experiments presented in Paper Two investigated the possibility that adding these sensory cues to a beverage might increase its expected satiety value. Experiment one explored the extent to which small additions of a natural polysaccharide thickener to a fruit-juice based beverage produced measureable and perceivable differences in beverage viscosity, rated thickness and creaminess. This study demonstrated that participants were able to perceive small increases in beverage viscosity as subtly thicker and creamier but equally palatable. Based on these findings two target thicknesses were selected for application in Experiment two, where eight test beverages were developed combining four levels of

sensory context (thin with low-creamy flavour, thin with high-creamy flavour, thick with low-creamy flavour and thick with high-creamy flavour) and two levels of energy content (higher- and lower-energy). Participants were asked to rate the sensory and hedonic characteristics of the beverages and to estimate the extent to which they expected them to deliver satiety. It was hypothesised that the subtle manipulations in thick and creamy taste and texture cues would increase the extent to which a beverage is expected to deliver satiety, independent of its actual energy content.

1.4.3 Paper three: Does modifying the thick texture and creamy flavour of a drink change portion size selection and intake?

Paper three explored the possibility that the sensorally enhanced anticipated satiating effect of a beverage could influence actual beverage intake. Research indicates that expectations of satiation and satiety are important for portion size selection, but this research is primarily based on computer-based tasks and not actual food selection and intake. Traditional laboratory studies of meal-size measure *ad libitum* consumption, where a person consumes a food or beverage from a ‘never ending’ large portion, often where visual cues for portion size are removed. However this method does not easily allow for a person’s expectations to influence intake, instead food intake is more likely to be a function of internal factors such as eating rate (affected by texture) and stomach distension. This does not represent realistic drinking situations when, for example, fruit juices, smoothies or soft drinks are self-served from larger cartons. Paper two measured self-selected portion size of beverages varying in subtle satiety-relevant sensory cues. Male and female participants attended the laboratory on four test days to consume a fixed breakfast and then consume as much as they liked of a test beverage two hours later. The iso-energetic beverages were presented in each of the four sensory contexts created in Paper two (thin/low-creamy flavour, thin/high-creamy flavour, thick/low-creamy flavour and thick/high-creamy flavour), and matched for other sensory characteristics such as sweet flavour, familiarity and pleasantness. Participants were asked to taste the beverages and evaluate their sensory and hedonic characteristics before consumption. Importantly participants’ self-selected their portion size to assess the impact of the beverage's sensory properties on this behaviour. The amount of each beverage selected and consumed was covertly measured on each test day and appetite sensations were measured throughout the test session. It was hypothesised that if a beverage with enhanced thick and creamy sensory characteristics is expected to be more

satiating than the same drink without these characteristics, then a person may select and actually consume less of that drink.

1.4.4 Paper four: Can satiety-relevant labelling improve the anticipated and actual satiating effect of a high-energy beverage with enhanced sensory characteristics?

Labelling is likely to influence the anticipated satiating effect of a beverage, but evidence that labels affect the actual satiating effect of a food or beverage is mixed. Satiety-relevant labels and slogans may not be successful at enhancing expected and actual satiety if they are not consistent with the expectations generated by the product's sensory characteristics and nutrient effects. Paper four investigated the satiating effect of a beverage maximised for satiety through the addition of nutrients and thick and creamy sensory characteristics with congruent and incongruent satiety-relevant labelling of the beverage as "stay-full" (high satiety) "Lighten" (low satiety). In this study female participants consumed a lower-energy (78 kcal) and higher-energy (279 kcal) beverage in one of two sensory contexts: thin/low-creamy or thick/creamy. Energy content was manipulated by adding protein and carbohydrate to the lower-energy beverage base and the beverages were labelled in one of three ways: no label, congruent label or incongruent label. In the congruent label condition the higher-energy beverage was labelled as "*Stay-full: feel fuller throughout the day*" and the lower-energy beverage labelled "*Lighten: drink between meals without filling you up*". The opposite was true in the incongruent label condition. Participants consumed the beverages (with and without labelling) in either a thin/less-creamy or thick/creamy sensory context and recorded their food intake using 24-hour diet diaries. The key outcome measures were the extent to which the beverage was expected to be filling and the actual satiety value of the beverage, which was indexed by both the size and time of the participants' next spontaneous meal, and also their total energy intake over the test day. It was hypothesised that labelled satiety messages would enhance the satiating effect of a high-energy beverage when they are in-line with their sensory characteristics and nutrient content.

1.4.5 Paper five summary: Fluid or fuel? The context of consuming a beverage is important for satiety.

This study examined the satiating effect of nutrients consumed as a beverage in the satiety-relevant context of a 'snack' compared to a 'drink' and considered whether this

would have a greater impact on satiety than adding thick and creamy sensory cues. Two hours after consuming a fixed portion breakfast, participants consumed a lower- (LE, 75kcal) and higher-energy (HE, 272kcal) version of a beverage (across two test days). The beverages were consumed in one of four beverage contexts: thin versions of the test-drinks were consumed as a “thirst-quenching drink”, “a filling snack”, or without additional information. A fourth group consumed subtly thicker versions of the beverages without additional information. The sensory characteristics of both the higher- and lower-energy versions were carefully matched such that participants were unaware of this manipulation. Sixty minutes after consuming the test-beverage participants returned to the laboratory for an *ad libitum* lunch session, where they could eat as much as they liked. Total lunch intake was measured alongside water intake throughout the test day. Rated appetite and sensory and hedonic evaluations of all the test foods were also measured, and care was taken to ensure participants believed the beverage context information they received. The key outcome measure was the extent to which participants in each of the four beverage context groups responded to the covert manipulation of beverage energy content, by adjusting their later lunch intake. It was anticipated that those participants consuming the beverages in the more satiety-relevant contexts (as a snack or with enhanced sensory characteristics) would be better able to respond to the energy difference.

2. Paper one

Exploring the sensory basis of satiety and thirst expectations across a range of food and beverage products

Keri McCrickerd¹, Nele Lensing¹ and Martin R. Yeomans¹

¹ *School of Psychology, University of Sussex, Brighton, BN1 9QH, UK*

2.1 Abstract

The expected impact of a food or drink on appetite can influence decisions around eating and the actual experience of satiation and satiety post-consumption. One suggestion is that beverages have a weak impact on appetite regulation because they are not expected to be satiating. The present study explored the idea that a food's expected impact on hunger, fullness and thirst is based in part on the sensory characteristics of the food itself. Female participants ($n = 118$) evaluated 40 widely available ready-to-eat food and beverage products (varying in physical characteristics, packaging, serving size and total energy content) for anticipated sensory characteristics, pleasantness and familiarity, alongside expected impact on immediate fullness, hunger after one hour and thirst both immediately and after one hour. Correlations revealed that the products that were more caloric and anticipated to be creamier were also expected to be more filling and hunger suppressing than the products expected to be less creamy and with a lower total energy content. Contrary to our prediction, beverage products were expected to be as satiating as other food products with similar total energy contents. The product's serving size and familiarity were not related to the expected impact on hunger and fullness. On the other hand, products anticipated to be less salty and thick were expected to reduce thirst more, and these were primarily beverage products, which had a large serving size. These results indicate that when faced with a selection of pre-packaged ready-to-eat food and beverage products, the extent to which these products are expected to impact hunger, fullness and thirst is influenced by the characteristics of the products. It is likely that the association between caloric beverages and thirst-reduction contributes to their weak satiating power.

2.2 Introduction

In an environment where food and drink is readily available, decisions about what and how much to consume will impact a person's ability to maintain a healthy body weight. An increasing amount of evidence suggests that beliefs about the potential satiating effect of a food are a key factor affecting energy intake regulation (Brunstrom *et al.*, 2010a; Brunstrom & Shakeshaft, 2009; Cassady *et al.*, 2012; Wilkinson *et al.*, 2012). Caloric beverages have been identified as having a particularly weak impact on appetite regulation (Almiron-Roig *et al.*, 2013; Flood-Obbagy & Rolls, 2009), possibly because they are not expected to be satiating (Mattes, 2005). The present study explored the anticipated satiating effect of a range of commonly consumed beverages and ready-to-eat food products.

The anticipated satiating effect of a food is linked to our previous experience. Physiologically, the anticipation of nutrients (characterised by cephalic-phase neural and hormonal responses to food cues) is in part learned from associations between the sensory characteristics of the food and its post ingestive effect (Booth, 1972; Woods, 1991, 2009). As a result the sight, smell and taste of that food come to trigger salivation and release of gastrointestinal and other hormones involved in subsequent nutrient processing. If consistent, these sensory-nutrient relationships may be explicitly expressed as expectations of satiation (the extent to which a food is expected to deliver fullness immediately) and satiety (the extent to which a food is expected to suppress hunger over time) for a given food (Blundell *et al.*, 2010; Brunstrom, 2007).

Although our understanding of how explicit expectations of satiation and satiety are acquired is limited (Hogenkamp *et al.*, 2012a; Hogenkamp *et al.*, 2012b; Wilkinson & Brunstrom, 2009; Yeomans *et al.*, 2014) the impact of these expectations on eating behaviour is now well documented: expectations are thought to guide both portion size selection and actual food intake (Brunstrom & Rogers, 2009; Brunstrom & Shakeshaft, 2009; Wilkinson *et al.*, 2012), independently of perceived volume and liking (Brunstrom *et al.*, 2010a), and alter our experience of satiety post-consumption (Brunstrom *et al.*, 2011; Cassady *et al.*, 2012). Perhaps the most consistent evidence that satiety expectations are learned with experience comes from research demonstrating that expectations of satiety increases with a food's rated familiarity (Brunstrom *et al.*,

2010b; Brunstrom *et al.*, 2008; Hardman *et al.*, 2011). Yet what was not considered in these studies is how people generate expectations about the satiating effect of foods that they are unfamiliar with or which they have never eaten. The existence of expectations prior to consumption of new products suggests that these expectations are not simply a consequence of direct experience with a specific food, but may be guided by characteristics of the new product that show similarities to other known foods.

In line with this idea, a growing body of evidence now links satiety expectations to certain sensory characteristics: foods perceived to be thicker (Hogenkamp *et al.*, 2011), chewier and saltier (Forde *et al.*, 2013) and heavier (Piqueras-Fiszman & Spence, 2012) were expected to be more satiating. Indeed, in a drink context McCrickerd, Chambers, Brunstrom and Yeomans (2012) demonstrated that adding subtly thicker and creamier sensory cues to a beverage (without affecting nutrient content) increased the expectation that the beverage would be filling and suppress hunger to a greater extent than the same drink without these added characteristics. Presumably these sensory cues are associated with certain post-ingestive effects, such that they can be used to estimate the satiating power of other foods with similar sensory characteristics. This would support the view that the sensory system acts as a nutrient sensor (Woods, 1991, 2009), directing eating behaviour to ensure the efficient consumption of nutrient rich or nutrient lacking foods. Beverages may not be expected to be satiating if they do not contain satiety-relevant sensory cues.

The present study aimed to consider whether beverages are expected to have a particularly weak satiating power and to investigate the extent to which the anticipated taste and texture characteristics (such as thickness, creaminess, sweet and salty) of a range of food and beverage products predict their expected impact on appetite. Participants evaluated 40 images of popular ready-to-eat products consisting of a range of liquid (waters, soft drinks, fruit juices), semi-liquid (soups, yogurts), semi-solid (jelly, porridge) and solid (chocolate, crisps, apple etc.) foods and beverages, for their anticipated sensory and hedonic characteristics and their expected impact on feelings of hunger, fullness and thirst (four outcome expectations: *fullness immediately*, *hunger after one hour*, *thirst immediately* and *thirst after one hour*). The food and beverage items were selected to represent a wide range of sweet and savoury products and a mixture of raw, modified and highly processed foods readily available in the UK.

2.3 Method

2.3.1 Participants

One hundred and nineteen female students and staff from the University of Sussex were recruited to take part in a study investigating “the interaction between food products and mood”. Participants had English as their first language, were mainly younger adults (mean age 21 years, $SD \pm 3$, range 18-38 years) and had an average BMI of 23.5 kg/m² ($SD \pm 4.0$, range 17.0-37.2 kg/m², where a BMI of <18 kgm⁻² is classed as underweight, 18-25 kgm⁻² healthy, 25-30 kgm⁻² overweight and 30+ kgm⁻² obese). Participants had a mean dietary restraint score of 10 ($SD \pm 6$, range 0-21, where possible scores range from 0 (low-restraint) to 21 (high-restraint), and disinhibition score of 8 ($SD = 3.1$, range 2-16, where possible scores range from 0 (low disinhibition) to 16 (high disinhibition), as measured by the Three Factor Eating Questionnaire (TFEQ: Stunkard & Messick, 1985). The research was approved by the University of Sussex Life Science Research Ethics Board.

2.3.2 Design

The study was conducted using a correlational design, where all data were collected as continuous variables. Participants rated the expected sensory characteristics (*thick, hard, creamy, sweet, bitter, salty*), *pleasantness and familiarity* of 40 food and drink products readily available in the UK, and also rated their anticipated effect of feelings of satiety and thirst: expected fullness immediately after consumption (*fullness immediately*); expected hunger one hour after consumption (*hunger +1*); expected thirst immediately after consumption (*thirst immediately*); expected thirst one hour after consumption (*thirst +1*). A measure of the product’s total energy content (kcal) and serving size (g) were also recorded for each of the food and beverage items in the quantities they were pictured.

2.3.3 Food and beverage product stimuli

Details of the 40 food and beverage stimulus are reported in Appendix 2.1. Products were selected to be a representative range of food and beverage products available in the UK, varying in texture, flavour, energy content, serving size and familiarity, and were primarily those that were ready to eat. In the task the foods and beverages were presented as a single portion, which in the majority of cases was the product in its

entirety, in or next to its original packaging either on a white plate, in a white bowl or a clear glass (depending on the product type). Photographs were taken of each item in a standard format to produce images measuring 654 x 490 pixels: examples of six of these are shown in Figure 2.1. and a large-scale example (80% of true size) is contained in Appendix 2.2.



Figure 2.1. Example images of six of the 40 food and beverage stimuli

2.3.4 Appetite ratings

All of the experimental task was programmed and ran in MATLAB R20112b. As part of this task, a series of computerised appetite ratings, disguised as “Mood Questions”, were collected in order to get a measure of each participant’s rated appetite before and after the main task. Participants were asked “How <target> do you feel right now?” and were instructed to respond by placing a marker along a 100 point Visual Analogue Scale (VAS) positioned in the middle of the screen. The scale response ranged from “Not at all <target>” (0) to “Extremely <target>” (100) and participants rated how *hungry*, *full* and *thirsty* they felt, and their *desire to eat*. These ratings were embedded amongst a range of mood related items (*tired*, *happy*, *headachy*, *anxious*, *nauseous*, *energetic*, and *alert*), which acted as distracter questions to the appetite measures. Only the appetite measures were included in analyses.

2.3.5 Anticipated sensory characteristics and Expectations of fullness, hunger and thirst

Participants rated how *familiar* each product was, and the extent to which they expected the products to taste *thick, creamy, sweet, salty, bitter* and *pleasant* (How <target> do you expect this to taste?). In addition to this, participants made four judgements about what they expected from consuming each of the products (the four outcome expectations). These expectation questions followed the same format: participants were asked to “Imagine you have just consumed a whole serving of the product” followed by one of four questions: “How full would you feel immediately afterwards?” (*fullness immediately*); “How hungry would you feel in 1 hour?” (*hunger +1*); “How thirsty would you feel immediately afterwards?” (*thirst immediately*); “How thirsty would you feel in 1 hour?” (*thirst +1*). As with the appetite questions, participants gave all of their responses on a 100 point VAS scale, with the end anchors “Not at all <target>” (0) to “Extremely <target>” (100). This task was part of the same MATLAB program as the appetite ratings.

2.3.6 Procedure

Testing took place Monday-Friday between 9:00-11:00 and 14:00-17:00 and all participants gave written informed consent and were instructed not to eat or drink anything but water for two hours before taking part. Compliance to the eating restrictions outside of the laboratory was not measured exclusively, and relied on participant reports prior to testing. Testing was conducted in air-conditioned testing cubicles using a Dell PC computer running Windows 7 with an 18-inch screen with a resolution of 1280x1024. As mentioned, the experimental task was completed in MATLAB R20112b.

Participants began by completing the first set of ‘mood questions’ to record their appetitive state. They were then presented with an instruction page, informing them that they would be rating 40 food and drink products for a number of characteristics. At this point the experimenter was called to give an example of the types of questions they would be asked. Participants were instructed that they would need to imagine consuming the entire food or beverage product that was presented in each image, both inside and outside of its container if necessary, except for one item (rice cakes) where they were only instructed to imagine consuming the three presented next to the packet.

Placed next to the computer screen was an example of the plate, bowl and glasses used in the images, and participants were instructed that they should refer to these to help them imagine the serving size presented. The picture-rating task involved participants viewing images of the 40 items, presented in a random order in the centre of a white screen. Eleven evaluations were made of each product, comprising the seven expected sensory and hedonic characteristics and the four judgements of expected fullness immediately, hunger in one hour, and thirst both immediately and 1 hour later, all made using VAS and in randomised order. The first rating was presented two seconds after each image was displayed. Participants could answer the questions in their own time with the instruction “to complete the rating please move the cursor along the line to the point that best reflects your judgement, and right click”, and once clicked the next question was presented. In order to discourage rapid responding, participants could only move on if they responded at least one second after the question was presented. Once complete, participants repeated the mood questions before filling out a paper version of the TFEQ. Height and weight were recorded prior to debriefing and receipt of £5 for taking part.

2.3.7 Analysis

The data from one individual failed to record so all analyses were conducted on data from the remaining 118 participants. The primary aim of the analysis was to explore the extent to which the characteristics of the food and beverage products predicted their expected impact on appetite, and to consider whether beverages were expected to have a particularly weak satiating power. In order to achieve this, data were initially collapsed across participants to create mean values across all of the variables, for each food and beverage product ($n = 40$).

Firstly, each of the 40 products mean scores on the four outcome measures (*fullness immediately*, *hunger +1*, *thirst immediately* and *thirst +1*) were plotted on scatter plots to assess how the expected impact on appetite differed across products (Figures 2.2 and 2.3). Then, the relationships between the four main outcomes variables and the expected sensory characteristics (*thick/hard texture*, *creamy*, *sweet*, *salty*, *bitter*, *pleasant*, *familiar*), *pleasantness*, *familiarity*, and the product’s *total energy content (kcal)* and *serving size (g)* were assessed using Pearson’s correlation confidences (Table

2.1). Finally, the product-specific variables that were found to significantly relate to the four outcome variables were entered into linear-regressions (one for each outcome expectation of hunger, fullness and thirst, presented in Tables 2.2-2.5), to assess the independence of these relationships. Each regression model was assessed for improvement over the mean model, multicollinearity and bias (see the *building the regression models* section of the results) and all regression coefficients are presented alongside bootstrapped 95% Confidence Intervals (CI).

One problem with collapsing the relationships between the product's sensory and nutrient characteristics and the expected impact on hunger, fullness and thirst across the food products is the loss of inter-participant variation. In the last part of the analysis we tried to account for this: Regression Coefficient Analysis (RCA: described by Lorch and Myers (1990: method 3) was used to assess whether any of the relationships identified in Table 2.1 were moderated by any of the following inter-participant characteristics (which could not be controlled for in the main regression analysis due to the assumption of independence): pre-test appetite (hunger, fullness, desire to eat and thirst), BMI and TFEQ Restraint and Disinhibition scores. This analysis was achieved in two steps: firstly, a simple regression was conducted for each participant to produce a series of unstandardized Beta's (regression weights) to describe the relationship between each sensory and nutrient variable and the four outcome expectations across all of the 40 products. The across-participant mean of these regression weights are presented in Table 2.6. Secondly, the regression weights were correlated (using Pearson's correlations) with each of the inter-participant variables: a significant correlation indicated that the strength of the relationship defined by the regression weights varied as a function of the participant characteristic.

2.4 Results

2.4.1 Expectations of satiation and thirst across the different food products

Figure 2.2 presents a scatter plot of the mean ratings of expected fullness and expected hunger after one hour for each food and drink product. The two expectations were very highly correlated indicating that the foods that were expected to be more filling were expected to have a greater hunger-suppressing effect after one hour. This also illustrates that products expected to be most satiating were the Dolmio pasta pot, the porridge pots and both standard and low fat soups. The Pot Noodle, Friji milkshake and the ice cream pot were all expected to be relatively satiating. On the other hand the Yakult, Babybel, SlimFast bar, both the ‘low sugar’ and standard Jelly Pots and the water (still and sparkling) were amongst those products expected to be least satiating. Many of the beverage products, such as Milk, PowerAde and Redbull were expected to be relatively satiating.

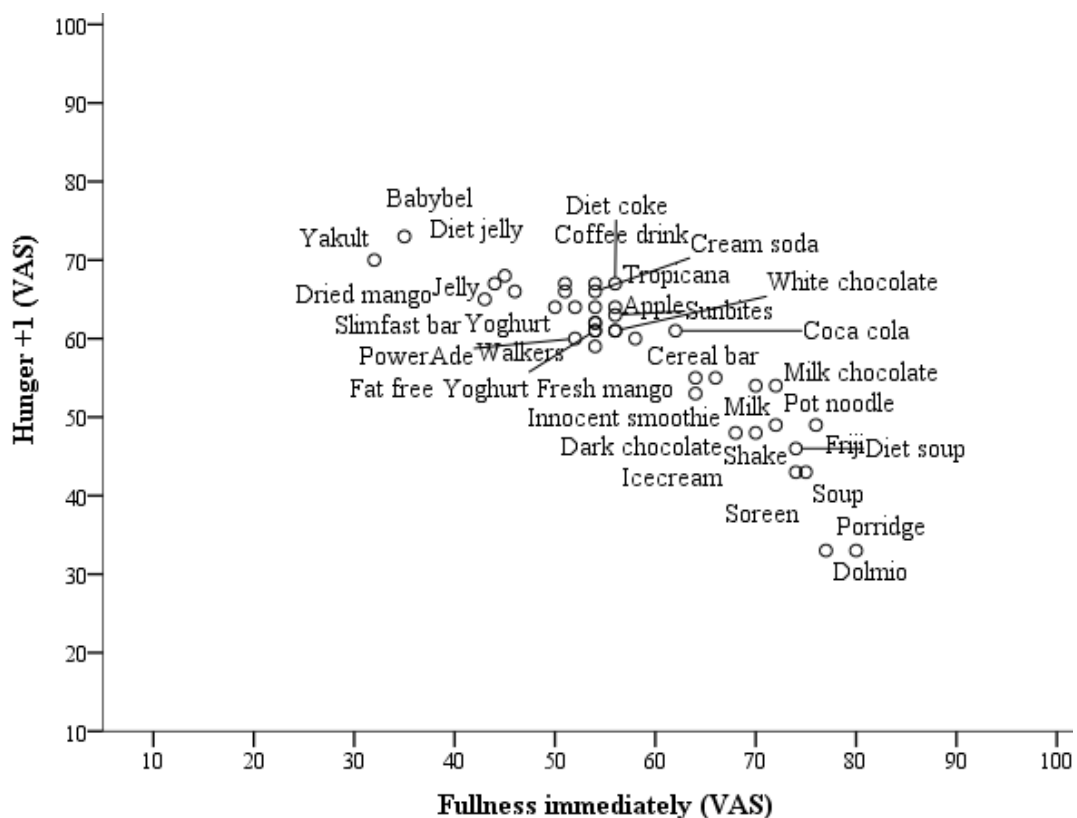


Figure 2.2 Scatter plot of the mean *fullness immediately* and *hunger +1* expectations for the 40 food and beverage products. The two expectations were highly correlated, $r = -0.909$, $p < .001$.

Both expected thirst ratings (*thirst immediately* and *thirst +1*) were positively correlated (see Figure 2.3). Unsurprisingly, the beverage products were expected to be most thirst-quenching, in particular still and sparkling water and PowerAde were expected to reduce thirst the most, both immediately and after one hour later. On the other hand, the popcorn, both types of crisps (Walkers and Sunbites), wasabi peas, Pot Noodle and all three types of chocolate bar (dark, milk and white chocolate bar) were the products expected to be the least thirst-quenching.

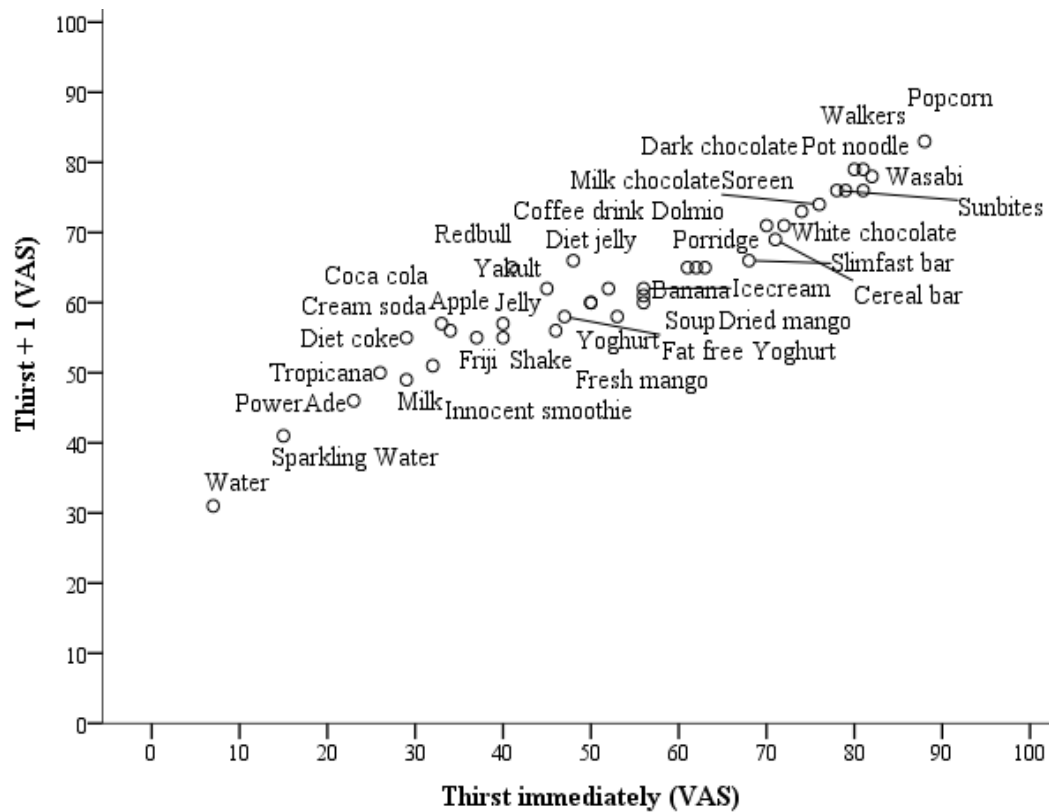


Figure 2.3 Scatter plot of the mean *thirst immediately* and *thirst +1* expectations for the 40 food and beverage products. The two expectations were highly correlated, $r = 0.960$, $p < .001$.

2.4.2 Exploring the relationships between sensory and nutrient characteristics of the products and expected impact on appetite

The top section of Table 2.1 reports the relationships (Pearson's correlation coefficients) between the product's characteristics and the four outcome expectations of fullness, hunger and thirst.

Table 2.1 The relationships between the products' characteristics and each of the hunger, fullness and thirst expectations.

<i>N</i> = 40	Creamy	Thick/hard	Sweet	Salty	Bitter	Pleasant	Familiar	Total energy (kcal)	Serving size (g)
Fullness	0.350*	0.112	0.056	0.081	-0.116	0.215	0.177	0.671**	0.281
Hunger 1 hour	-0.359*	-0.160	-0.009	-0.174	0.103	-0.171	-0.026	-0.703**	-0.156
Thirst	0.030	0.765**	-0.256	0.670**	0.255	0.041	-0.257	0.461**	-0.756**
Thirst 1 hour	-0.018	0.663**	-0.217	0.689**	0.348*	-0.063	-0.258	0.443**	-0.713**
Creamy	/	0.150	0.282	-0.233	-0.190	0.275	-0.035	0.383*	-0.020
Thick/hard		/	-0.024	0.271	0.183	0.290	-0.102	0.386*	-0.755**
Sweet			/	-0.700**	-0.237	0.333*	-0.027	0.064	0.019
Salty				/	0.178	-0.181	-0.170	0.276	-0.243
Bitter					/	-0.472**	-0.252	0.016	-0.219
Pleasant						/	0.473**	0.239	-0.123
Familiar							/	0.027	0.157
Total energy (kcal)								/	-0.035
Serving size (g)									/

* Significant at $p > .05$; ** Significant at $p < .001$

Expected fullness immediately after consumption (*fullness immediately*) and expected hunger after one hour (*hunger +1*) were both significantly correlated with the product's expected creaminess and its actual energy content; products expected to be creamy and with a higher total energy content per serving were expected to be more filling and to suppress hunger to a greater extent than lower energy, less creamy products. There were no significant relationships between the rest of the products characteristics (taste and texture, pleasantness, familiarity and serving size) with the products expected impact on fullness and hunger.

The products' expected impact on thirst ratings both immediately (*thirst immediately*) and after one hour (*thirst +1*) were significantly positively correlated with anticipated saltiness and thick/hard texture, but also to the products total energy content and serving size. Expected thirst + 1 was also significantly correlated with anticipated bitterness, but thirst immediately was not. Anticipated creaminess, sweetness, pleasantness and familiarity were not significantly correlated with expectations of thirst.

The lower part of Table 2.2 details the correlations between the independent product variables. These inter-correlations are important when considering the independence of potential predictors of the four outcome expectations in subsequent regression models (including potential causes of multicollinearity). The products' anticipated creaminess and thick/hard texture were both positively correlated with its total energy content, such that products expected to be creamier and thicker/harder contained more energy. Thick/hard texture was also strongly correlated with the products' serving size; products served in the larger sizes were those expected to be less thick/hard. This is because the liquid beverage products tended to be served in larger portions. Products expected to be sweeter were expected to be less salty and more pleasant. Pleasantness was also positively correlated with the products familiarity and negatively correlated with bitterness.

2.4.3 Building regression models

Regression models were built to identify the independence of the relationships between the product's characteristics and each of the outcome expectations, described in Table 2.1: expected *fullness immediately*, *hunger +1*, *thirst immediately* and *thirst +1*. Thus,

anticipated creaminess and total energy content were both entered into the regression model explaining expectations of fullness immediately and hunger +1.

The regression model for expected thirst immediately after consumption contained anticipated saltiness and thick/hard texture, alongside the product's total energy content and serving size. The same variables were entered in the model for expected thirst one hour later, with anticipated bitterness as an additional variable. However, there was evidence that the final models for both expectations of thirst were distorted by collinearity caused by the strong significant relationship identified between the product's serving size and expected thick/hard texture (see Table 2.1: mean VIF = 2.2 for thirst immediately and 2.0 for thirst +1). Seemingly, the products perceived to be thinner (i.e. beverages) tend to be served in a larger portion (g). There was no acceptable way to reduce collinearity other than to remove one of the variables from the model. Because the primary aim of the study was to determine the roles of sensory properties on expectations of satiety and thirst, serving size was removed from both regression models and thick/hard texture kept.

2.4.4 Predictors of expected fullness immediately and hunger +1

The regression models predicting expected fullness immediately and hunger + 1 are presented in Table 2.2 and 2.3 respectively. Analysis revealed that creaminess was not a significant independent predictor of expected fullness when the effect of the product's actual energy content was controlled for. Instead, the product's total energy content was the best independent predictor, with foods with a higher total energy content expected to be more filling. The same was seen for expectations of hunger. When included together in the regression model the product's creaminess was a poor independent predictor of expected hunger, while total energy content was a significant positive predictor of this expectation. Together, anticipated creaminess and total energy content accounted for 46% and 50% of the variance in expectations of fullness immediately and hunger after one hour respectively.

Table 2.2 Summary of the regression predicting expected *fullness immediately*

	<i>b</i> [95% CI]	SE <i>b</i>	β	<i>p</i> -value
Constant	45.45 [39.80, 51.10]	2.79		< .001
Creaminess	0.04 [-0.06, 0.15]	0.05	0.11	.413
Total energy (kcal)	0.08 [0.05, 0.12]	0.02	0.63	< .001

$R^2 = 0.461$ for $p = .001$, meaning that together the products expected creaminess and total calories accounted for 46 % of the variance in expected fullness ratings (creaminess was 12 % while calories 34%). This model was significantly better at predicting expected fullness ratings than the mean model, $F(2,37) = 15.81, p < .001$.

Table 2.3 Summary of the regression predicting expected *hunger +1*

	<i>b</i> [95% CI]	SE <i>b</i>	<i>B</i>	<i>p</i> -value
Constant	69.49 [64.95, 73.91]	2.21		< .001
Creaminess	-0.04 [-0.12, 0.05]	0.05	-0.11	.406
Total energy (kcal)	-0.07 [-0.05, -0.12]	0.02	-0.66	< .001

$R^2 = 0.503$, meaning that creaminess and total calories accounted for 50 % of the variance in expected hunger ratings. This model was significantly better at predicting expected fullness ratings than the mean model, $F(2,37) = 18.76, p < .001$.

2.4.5 Predictors of expected thirst immediately and one hour later

The regression models for expected feelings of thirst immediately and after one hour are summarised in Tables 2.4 and 2.5 respectively. The product's expected saltiness and thick/hard texture were both significant independent predictors of expected thirst immediately after consumption, while the total energy content was a poor independent predictor of this belief. Together, these variables accounted for 82% of the variance in expectations of thirst immediately after consumption. Similarly, the products' anticipated thick/hard texture and salty taste characteristics were also significant independent predictors of expected thirst after one hour, whereas bitter taste and total

energy content were poor independent predictors of this belief. Together these variables accounted for 83% of the variance in expected thirst after one hour.

Table 2.4 Summary of the regression predicting expected *thirst immediately*

	<i>b</i> [95% CI]	SE <i>b</i>	<i>B</i>	<i>p</i> -value
Constant	16.80 [9.98, 23.62]	3.36		< .001
Salty	0.42 [0.29, 0.55]	0.06	0.48	< .001
Thick/hard	0.58 [0.43, 0.73]	0.08	0.60	< .001
Total energy (kcal)	0.02 [-0.01, 0.06]	0.02	0.10	.211

$R^2 = 0.824$, meaning that together, saltiness, thick/hard texture and total energy accounted for 82% of the variance in expected thirst ratings. This model was significantly better at predicting expected thirst ratings than the mean model, $F(3,36) = 56.34$, $p < .001$.

Table 2.5 Summary of the regression predicting expected *thirst +1*

	<i>b</i> [95% CI]	SE <i>b</i>	β	<i>p</i> -value
Constant	44.25 [37.66, 49.81]	3.72		< .001
Salty	0.23 [0.17, 0.28]	0.07	0.47	< .001
Thick/hard	0.22 [0.12, 0.35]	0.08	0.59	< .001
Bitter	0.13 [-0.09, 0.35]	0.12	0.06	.401
Total energy (kcal)	0.36 [-0.08, 0.70]	0.02	0.10	.189

$R^2 = 0.828$ meaning that together the products expected salty, thick/hard and bitter characteristics, alongside its actual energy content, accounted for 83% of the variance in ratings of expected thirst after 1 hour. This model was significantly better at predicting expected thirst ratings than the mean model, $F(4,35) = 42.11$, $p < .001$.

2.4.6 The role of cross-participant appetite, BMI and eating style

Whether participants' individual characteristics moderated any of the cross-product relationships between the sensory and nutrient characteristics and each of the four outcome expectations is reported in Table 2.6. This revealed that the positive relationship between the products' perceived creaminess and expectations of fullness immediately was significantly moderated by the participants TFEQ restraint scores: the higher the participant's restraint score the weaker the relationship between creaminess and expected fullness. None of the other participant characteristics (disinhibition, BMI or pre-test appetite) moderated any of the other relationships with expected fullness. The only participant characteristic to moderate the negative relationship between creaminess and expected hunger +1 was disinhibition scores; the higher the participants' disinhibition scores the weaker the relationship. Restraint, BMI or pre-test appetite did not moderate this relationship. Furthermore, the relationships between the product's characteristics and expected impact on thirst (both thirst immediately and thirst +1) were not moderated by any of the participant characteristics (see Table 2.6).

Table 2.6 The relationships between the participants' appetite, BMI and restraint and disinhibition scores with each of the beta values representing the relationship between each of the four outcome expectations and the product's characteristics.

<i>N</i> = 118		Mean beta	Individual characteristics						
			Fullness	Hunger	Desire to eat	Thirst	BMI	TFEQ_R	TFEQ_D
Fullness Immediately	Creaminess (VAS)	0.11	-0.003	0.205	0.095	0.036	-0.003	-0.254*	-0.230
	Total energy (kcal)	0.09	0.061	0.118	0.090	0.166	0.006	-0.095	-0.107
Hunger +1	Creaminess (VAS)	-0.10	-0.015	0.013	<0.001	0.105	-0.033	-0.025	0.325*
	Total energy (kcal)	-0.08	-0.018	-0.034	-0.053	0.122	0.009	0.002	0.118
Thirst immediately	Salty (VAS)	0.47	-0.001	-0.088	-0.007	-0.123	-0.039	-0.018	-0.043
	Thick/hard (VAS)	0.44	-0.145	0.002	0.054	-0.094	-0.191	-0.146	-0.015
	Total energy (kcal)	0.10	-0.014	-0.038	-0.027	-0.042	-0.161	-0.061	-0.044
	Serving size (g)	0.11	0.202	-0.079	-0.133	0.123	0.194	0.122	0.189
Thirst +1	Salty (VAS)	0.26	0.147	-0.183	-0.160	-0.182	-0.082	0.234	-0.092
	Thick/hard (VAS)	0.20	-0.014	-0.067	-0.024	-0.114	-0.152	0.025	-0.056
	Bitter (VAS)	0.15	-0.134	-0.041	-0.032	-0.005	0.004	0.028	-0.040
	Total energy (kcal)	0.05	-0.068	-0.139	-0.148	-0.054	-0.069	0.061	-0.046
	Serving Size (g)	-0.05	0.006	-0.004	-0.046	0.143	0.177	-0.085	0.106

* Significant at $p > 0.05$. The regression weights (mean unstandardized betas) describe the strength and direction of the relationship (averaged across the 118 participants) between each of the product variables and the four outcome variables (originally identified in Table 2.1). A regression weight of zero indicates no relationship. Each participant's regression weights were correlated with the within-participant characteristics (rated appetite, BMI, TFEQ restraint (R) and disinhibition (D) scores); a significant correlation indicates that the strength of that relationship is significantly moderated by the within-participant characteristic.

2.5 Discussion

Key findings from the current study indicate that across a range of commonly consumed food and drink products, the extent to which a food or beverage is expected to be filling and to suppress hunger was best predicted by their actual energy content. This suggests that people have a good idea of the energy content of food and drink products, relative to each other, and this knowledge can inform, in part, its expected satiating power. On the other hand, the product's anticipated impact on thirst was best predicted by their anticipated salty and thicker/hard sensory characteristics, and not their total energy content with beverages generally expected to be the most thirst-quenching products. This is in line with previous study reporting that a range of beverages with different energy contents (milk, regular cola, orange juice and sparkling water) all had the same impact on thirst (Almiron-Roig & Drewnowski, 2003). Caloric beverages are interesting because they have the capacity to be both satiating and thirst quenching, and these data indicate that people can acknowledge this when considering their potential impact on appetite. But this also suggests that anything that increases thirst (such as consuming salty snacks or foods) could promote passive over-consumption if, for example, a person chooses a high-calorie beverage over low-calorie option to quench their thirst.

In the present study, higher energy beverages were generally expected to be relatively satiating compared to the other food products: for example Friji (a strawberry milkshake, 306 kcal, 471 g) was expected to be one of the most satiating products, similar to the Pot Noodle (115 kcal, 90g) and Tomato Soup (225 kcal, 400g) (see Figures 2.2 and 2.3). Furthermore, the Innocent Smoothie (170 kcal, 250 g) was expected to be similarly satiating as the Dark Chocolate bar (201 kcal, 35 g). It is notable that while these products were fairly well matched for their expected impact on hunger and fullness, they varied widely in their total energy content and serving size, with beverages tending to be served in larger portions, suggesting that on a gram-for-gram, beverages may be expected to be less satiating than other food forms. Yet, overall the product's actual serving size (g) was not significantly related to expectations of satiation and satiety. To explore this further, we recommend comparing, calorie-for-calorie, the expected satiating power of a range of equicaloric solid, semi-solid and liquid foods and beverages, using the product's resulting serving size as a covariate to

evaluate whether this variable moderates the role of food form on satiety expectations. Although, it could be argued that assessing the expected satiating value of foods and beverages in their actual serving size is more realistic of every-day eating situations.

One way serving size might impact expectations of satiation and satiety is if it influences the perceived volume of the food that is to be consumed. Previous research reported that foods perceived to have a larger volume were expected to be more satiating (Brunstrom, Collingwood & Rogers, 2010a). However, the foods evaluated in the study of Brunstrom *et al.* (2010a) still significantly varied in the extent to which they were expected to be filling *after* the differences in perceived volume were taken into account. Thus, perceived volume alone is unlikely to explain why different foods are expected to differentially impact appetite. Moreover, Hardman, McCrickerd and Brunstrom (2011) found that a child's perceived volume of a familiar snack only corresponded to its expected satiation if the snack was particularly unfamiliar, suggesting that perceived volume might only be a relevant cue for the potential satiating effect of a food when previous experience of consumption is limited. Assuming that perceived volume corresponded well to the actual serving size of a food, it is possible that, as adults aged between 18-38 with many years of consuming different type of foods and beverages, the participants in the present study had little need to use perceived volume to guide beliefs about the satiating effect of the foods and beverages.

A principle aim of the present study was to explore the sensory basis to expectations of hunger, fullness and thirst, and findings suggest that products anticipated to be creamier were expected to be the more filling and hunger-suppressing. This is in line with recent evidence indicating that foods perceived to be thicker (Hogenkamp *et al.*, 2011; McCrickerd *et al.*, 2012) chewier and saltier (Forde *et al.*, 2013) were expected to be more filling. However, in the current study creaminess was not a good predictor of expectations when the effect of the product's total energy content was taken into account. This is likely to be due to the inter-correlation between perceived creaminess and energy content: the product's with higher to total energy contents were expected to be creamier (Table 2.1). Indeed, creaminess is a multi-modal sensory characteristic that has been frequently linked to a food's fat (Chojnicka-Paszun, de Jongh, & de Kruif, 2012; De Wijk, Terpstra, Janssen, & Prinz, 2006; Kirkmeyer & Tepper, 2005; Mela, 1988; Picciano, 1998) and protein (Bertenshaw *et al.*, 2008, 2009, 2013) content. This

suggests that creamy sensory characteristics could be a useful cue for energy in foods and beverages.

With repeated consumption of foods, humans and other animals learn to associate the sensory experience of food, such as perceived creaminess, with its post-ingestive effects (Booth, 1972; Woods, 1991, 2009), which can be expressed by explicit expectations of satiation and satiety (Brunstrom, 2005, 2007). This could explain why previously, foods rated as more familiar tend to be expected to be more satiating (Brunstrom *et al.*, 2010b; Brunstrom *et al.*, 2008; Hardman *et al.*, 2011). However, familiarity with the food and beverage products in this study was not significantly related to their expected impact on hunger and fullness, which was initially surprising given the large range in mean familiarity scores achieved (18–94 on the 100-point VAS, where the ‘Fitness Shake’ was the least familiar product and the apple and the banana the most familiar). There are several possible reasons for this. Firstly, recent evidence suggests that consuming a food to fullness is more important for expectations of fullness than general familiarity with that food (Irvine *et al.*, 2013). It is possible that some of the snack-type products and beverages evaluated in this study were familiar but had not been eaten to fullness; including measure of this form of familiarity might have provided a useful clarification. However, since people can still generate prior expectations about unfamiliar foods (Brunstrom *et al.*, 2010b), an alternative possibility is that satiety expectations are not just a consequence of direct experience with a food or beverage, but also guided by sensory and labelled cues a person may have encountered whilst consuming other similar known foods. With this additional information product-specific familiarity may be less important.

Learning that certain sensory characteristics can predict the presence of nutrients in a food or beverage is based on the assumption that sensory-nutrient relationships are fairly consistent within our diet. Recently, van Dongen and colleagues (2012) reported that across a range of foods commonly consumed in the Netherlands perceived taste characteristics generally mapped on well to the actual nutrient content. For example, perceived sweetness and saltiness were positively associated with the sugar and sodium content when assessed across a range of foods (van Dongen *et al.*, 2012). Given these taste-nutrient relationships, however, why were sweet and salty taste cues not related to expectations of fullness and hunger in the present study? Firstly, the majority of the

products evaluated in this study could be classed as sweet rather than savoury; so one possibility is that saltiness may have been a less relevant cue for satiation and satiety in this instance. So far only one study has reported that foods perceived to be saltier were expected to be more filling (Ford *et al.*, 2013), but this study only used savoury meal components, and so saltiness might have been a particularly relevant cue for satiation, perhaps signalling protein content (van Dongen *et al.*, 2012).

Finding that sweetness was not linked to expectations of satiety was also contrary to previous research (Hogenkamp *et al.*, 2011) but might reflect the ‘processed’ nature of many of the products used in this study, which were primarily pre-packaged and contained a number of food additives, particularly artificial sweeteners (a common feature of most mass produced foods in a westernised diet). In the current study, products such as Diet Coke and the Hartley’s jellies were sweet tasting but contained virtually no nutrients, which was emphasised by “Diet”, “Sugar Free”, “10 Calories” and “Low Calorie” labelling (see Appendix 2.2 for an example of the visible labelling at 80% of the real-size image). Thus, finding that anticipated sweet-taste did not influence satiety expectations might reflect and the participant’s awareness that sweetness is not necessarily associated with calories in these type of products, a belief generated in part by visible cues from labels. Indeed, product variables (creaminess and total energy content) did not account for all of the variance in expectations of fullness and hunger (46% and 50% respectively) and visible labelled information, such as such as ‘diet’, ‘low fat’, ‘high protein’, ‘wholegrain’ and ‘light’, may have contributed to participants’ beliefs (Fay *et al.*, 2011b).

Finally, an interesting outcome of the study was the preliminary evidence that characteristics of the participants themselves, such as self-report dietary restraint and disinhibition, and rated hunger could influence the expression of the relationships between characteristics of a food or beverage and their expected impact on appetite. There is some evidence to suggest that individuals with higher dietary restraint are less able to learn about the satiating effect of foods (Brunstrom & Mitchell, 2007), perhaps because focusing on the cognitive control of food intake reduces sensitivity to the actual satiating effects of food post-consumption (Yeomans, 2010b). Understanding how individual differences in appetite and eating styles moderate the expression of this learning will be important to understand how expectations are likely to impact appetite

control in the real world. It should be noted, however, that this was correlational research, measuring beliefs only and conducted solely on female participants with a limited selection of food product, which means generalisation of these findings to wider populations and other food products is limited for now. Despite this, our evidence clearly highlights the need to understand how both the features of the foods we consume and the individual consumer influence satiety-relevant expectations. Pursuing this further will place research in a better position to consider how these beliefs are likely to influence actual eating behaviours.

2.5.1 Acknowledgements

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2.5.2 Authors contributions

KMc designed the study with MR.Y. KMc and NL prepared the study materials. NL collected the data with the assistance of KMc. KMc analysed the data and drafted the manuscript.

Appendix 2.1 Summary of the 40 food and drink products used in the study and their nutrient contents.

Food and beverage product	Serving Size	Total energy (kcal)	Familiarity	Pleasant	Creamy	Sweet	Salty	Thick/hard
Coffee drink (Starbucks)	197 ml	140.0	42	49	68	13	50	24
Coca-Cola (The Coca-Cola Company)	330 ml	138.6	92	70	12	12	87	10
Diet Coke (The Coca-Cola Company)	330 ml	1.7	86	57	9	11	75	7
PowerAde (The Coca-Cola Company)	500 ml	80.0	59	50	6	15	79	6
Redbull (Red Bull GmbH)	250 ml	112.5	82	43	6	14	78	8
Tropicana (Orange, Tropicana Products Inc.)	330 ml	158.4	89	83	21	8	75	21
Cream Soda (Sainsbury's UK)	330 ml	6.6	43	52	46	13	77	10
Yogurt (Muller Dairy Limited, UK)	135 g	199.8	83	83	83	8	82	39
Fat-free yogurt (Muller Dairy Limited, UK)	175 g	91.0	69	71	83	10	73	34
Apple (Sainsbury's, UK)	112 g	51.5	94	79	8	6	75	74
Fresh mango (Sainsbury's, UK)	145 g	110.2	80	80	21	7	80	48
Strawberry Fiji (Dairy Crest Limited, UK)	471ml	306.2	69	70	85	7	87	45
Innocent Smoothie (The Coca-Cola Company)	250 ml	170.0	70	81	44	9	77	45
Shake (Multipower, UK)	330 ml	165.0	18	50	74	13	76	39
Diet soup (Tomato, Sainsbury's UK)	400 g	156.0	68	70	64	48	42	29
Soup (Cream of Tomato, Sainsbury's UK)	400 g	228.0	76	70	72	48	44	33
Semi-skimmed milk (Sainsbury's UK)	250 ml	125.0	88	57	74	6	37	25
Ice-cream (Ben & Jerry's)	150 g	225.0	70	86	88	9	90	48
Banana (Sainsbury's UK)	113 g	116.4	94	75	43	5	66	48
Yakult (Yakult UK Ltd)	65 ml	42.9	55	52	60	14	60	24

Appendix 2.1 continued

Food and beverage product	Fullness Immediately	Hunger +1	Thirst Immediately	Thirst +1
Coffee drink (Starbucks)	54	67	48	66
Coca-Cola (The Coca-Cola Company)	62	61	33	57
Diet Coke (The Coca-Cola Company)	56	67	29	55
PowerAde (The Coca-Cola Company)	52	60	23	46
Redbull (Red Bull GmbH)	54	61	41	65
Tropicana (Orange, Tropicana Products Inc.)	54	64	26	50
Cream Soda (Sainsbury's UK)	54	66	34	56
Yogurt (Muller Dairy Limited, UK)	54	62	53	58
Fat-free yogurt (Muller Dairy Limited, UK)	54	61	47	58
Apple (Sainsbury's, UK)	56	64	40	57
Fresh mango (Sainsbury's, UK)	58	60	46	56
Strawberry Fiji (Dairy Crest Limited, UK)	76	49	37	55
Innocent Smoothie (The Coca-Cola Company)	64	55	32	51
Shake (Multipower, UK)	70	48	40	55
Diet soup (Tomato, Sainsbury's UK)	74	46	52	62
Soup (Cream of Tomato, Sainsbury's UK)	75	43	56	61
Semi-skimmed milk (Sainsbury's UK)	72	54	29	49
Ice-cream (Ben & Jerry's)	68	48	56	62
Banana (Sainsbury's UK)	66	55	56	60
Yakult (Yakult UK Ltd)	32	70	45	62

Appendix 2.1 continued.

Food and drink products	Serving size	Total energy (kcal)	Familiarity	Pleasant	Creamy	Sweet	Salty	Thick/hard
Diet jelly (Hartley's, Premier Foods UK)	175 g	8.8	48	69	17	10	81	30
Jelly (Hartley's, Premier Foods UK)	125 g	100.0	59	70	18	9	83	29
Dried mango (Yu! Elite healthy Foods, UK)	24 g	87.4	27	61	12	13	72	47
SlimFast bar (Unilever)	26 g	93.6	26	60	37	17	75	63
Babybel (Bel UK)	20 g	60.8	77	64	70	43	22	53
Sparkling Water (Sanpellegrino S.p.A)	500 ml	0.0	63	47	4	11	12	7
Water (Sainsbury's, UK)	500 ml	0.0	95	71	2	2	6	3
Porridge pot (Quaker)	50 g	189.5	73	66	69	23	52	46
Dolmio (Mars Inc.)	300 g	300.0	64	76	32	54	32	38
Pot noodle (Unilever)	90 g	115.2	60	54	24	75	27	35
Dark chocolate (Sainsbury's UK)	35 g	201.3	75	55	35	18	48	76
Milk chocolate (Green & Blacks)	40 g	220.8	75	83	68	12	82	75
Soreen (McCambridge Group)	64 g	225.3	56	66	29	27	69	53
Fruit bar (Jordan Cereals)	45 g	166.5	63	64	12	17	71	66
White chocolate (Divine Chocolate Company)	45 g	243.0	71	84	80	8	88	72
Popcorn (Sainsbury's UK)	11 g	52.1	47	64	8	88	14	49
Sunbites (Walkers)	28 g	134.1	62	75	20	70	25	64
Crisps (Walkers)	33 g	173.2	89	74	9	73	17	56
Wasabi peas (The Cooperative, UK)	50 g	195.0	40	34	12	66	16	67
Rice cakes (Kallo)	24 g	93.1	67	52	7	57	17	59

Appendix 2.1 continued

Food and drink products	Fullness Immediately	Hunger +1	Thirst Immediately	Thirst +1
Diet jelly (Hartley's, Premier Foods UK)	45	68	50	60
Jelly (Hartley's, Premier Foods UK)	44	67	50	60
Dried mango (Yu! Elite healthy Foods, UK)	43	65	61	65
SlimFast bar (Unilever)	46	66	68	66
Babybel (Bel UK)	35	73	62	65
Sparkling Water (Sanpellegrino S.p.A)	51	66	15	41
Water (Sainsbury's, UK)	51	67	7	31
Porridge pot (Quaker)	80	33	63	65
Dolmio (Mars Inc.)	77	33	70	71
Pot noodle (Unilever)	72	49	80	79
Dark chocolate (Sainsbury's UK)	64	53	79	76
Milk chocolate (Green & Blacks)	70	54	76	74
Soreen (McCambridge Group)	74	43	72	71
Fruit bar (Jordan Cereals)	56	61	71	69
White chocolate (Divine Chocolate Company)	56	61	74	73
Popcorn (Sainsbury's UK)	54	62	88	83
Sunbites (Walkers)	56	63	78	76
Crisps (Walkers)	50	64	81	79
Wasabi peas (The Cooperative, UK)	54	59	82	78
Rice cakes (Kallo)	52	64	81	76

Appendix 2.2 An example product image (Hartley's 'diet' jelly) at 80% of the original size presented in the picture task.



3. Paper two

Subtle changes in the flavour and texture of a drink enhance expectations of satiety

Keri McCrickerd^{1*}, Lucy Chambers¹, Jeffrey M. Brunstrom², Martin R. Yeomans¹

¹ *School of Psychology, University of Sussex, Brighton, BN1 9QH, UK*

² *Nutrition and Behaviour Unit, School of Experimental Psychology, University of Bristol, 12a Priory Road, Bristol, BS8 1TU, UK*

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3.1 Abstract

The consumption of liquid calories has been implicated in the development of obesity and weight gain. Energy-containing beverages are often reported to have a weak satiety value: one explanation for this is that because of their fluid texture they are not expected to have much nutritional value. It is important to consider what features of these beverage can be manipulated to enhance their expected satiety value. Two studies investigated the perception of subtle changes in a beverage's viscosity, and the extent to which thick texture and creamy flavour contribute to the generation of satiety expectations. Participants in the first study rated the sensory characteristics of 16 fruit beverages of increasing viscosity. In study two, a new set of participants evaluated eight versions of the fruit beverage, which varied in thick texture, creamy flavour and energy content, for sensory and hedonic characteristics and satiety expectations. In study one, participants were able to perceive small changes in beverage viscosity that were strongly related to the actual viscosity of the test drinks. In study two, the thick versions of the beverage were expected to be more filling and have a greater expected satiety value, independent of the beverage's actual energy content. Creamy flavour additions enhanced the extent to which the beverage was expected to be filling to a lesser extent, but did not affect its expected satiety. These results indicate that subtle manipulations of texture and creamy flavour can increase expectations that a fruit drink will be filling and suppress hunger, irrespective of the beverage's energy content. A thicker texture enhanced expectations of satiety to a greater extent than a creamier flavour, and may be one way to improve the anticipated satiating value of energy-containing beverages.

3.2 Introduction

In the UK beverages account for approximately 18% of an adults daily intake (Ng *et al.*, 2012) and evidence that energy-yielding beverages have a weak satiety value suggests that the ‘fluid calories’ in our diet could be a quiet contributor to obesity and weight gain (Mattes, 2006a). A variety of studies indicate that energy consumed in liquid form fails to adequately suppress subjective appetite (Hulshof *et al.*, 1993; Leidy *et al.*, 2010) or reduce subsequent food intake (Mattes, 1996; Mourao *et al.*, 2007; Tournier & Louis-Sylvestre, 1991) compared to equi-caloric solid food. However, other studies have reported no relationship between food form and its satiety value (Almiron-Roig *et al.*, 2003; Almiron-Roig *et al.*, 2004), though a general criticism of studies in this field is that they often compare dissimilar foods (e.g. calorie-matched cola vs. cookies) across a range of food contexts (e.g. beverage vs. snack), and do not quantify differences in the cognitive and sensory evaluations of these foods (Cassady *et al.*, 2012; Mattes, 2005). Therefore it is important to consider what it is about these features of energy-yielding liquids that limit their satiety value.

Because of their fluid nature, beverages require less oral processing time than do semi-solid and solid caloric equivalents and as a result beverages are consumed fairly quickly, minimising oro-sensory exposure (Zijlstra *et al.*, 2008). Although increasing oral processing time may not necessarily lead to a reduction in the amount of a food that is consumed (Martin *et al.*, 2007), oro-sensory exposure is important for the development of satiety (Cecil *et al.*, 1998; Cecil, Francis, & Read, 1999): the thought, sight, smell and taste of food triggers a cascade of anticipatory salivary and gastrointestinal responses which improves the efficiency of nutrient processing and enhances the experience of satiety (Giduck, Threatte, & Kare, 1987; Mattes, 1997, 2006c; Woods, 1991).

Oro-sensory exposure to food is thought to trigger anticipatory responses because animals, including humans, learn to associate the sensory characteristics of food with its caloric value post-consumption (Birch & Deysher, 1985; Booth *et al.*, 1982; Shaffer & Tepper, 1994; Yeomans *et al.*, 2005) and these associations are likely to influence explicit expectations about the effect a food will have on appetite (Blundell *et al.*, 2010; Brunstrom *et al.*, 2008), including how filling a food is likely to be (expected satiation)

and the extent it will stave off hunger until the next meal (expected satiety). Such expectations have been shown to influence appetitive satisfaction and portion size selection (Brunstrom *et al.*, 2011; Brunstrom & Rogers, 2009; Brunstrom & Shakeshaft, 2009) and seem to be more strongly influenced by certain sensory characteristics. For example, a food is expected to be more filling when it is perceived to be heavier (Piqueras-Fiszman & Spence, 2012) or thicker in texture (Hogenkamp *et al.*, 2011). One reason why beverages are reported to have a weak satiety value may be because due to their fluid texture they are not expected to have much nutritional value (Mattes, 2005, 2006a).

Studies indicate that ‘thick’ beverages suppress hunger to a greater extent than an equi-caloric flavour matched ‘thin’ versions (Mattes & Rothacker, 2001; Zijlstra *et al.*, 2009b) and recent research suggests that the sensory characteristics of a beverage interact with its post-ingestive effects to influence satiety. Yeomans and Chambers (2011) reported that a high-energy liquid preload suppressed intake at a later meal to a greater extent than a low-energy equivalent, but only when the beverage had a thick texture and creamy flavour. Furthermore, when participants consumed the low energy version with thick and creamy sensory characteristics they ate more at test meal than after the low energy version without the enhanced sensory context. The researchers argue that thick and creamy sensory characteristics predicted the delivery of nutrients, generating expectations that these drinks will be filling which acted to enhance the experience of satiety when energy had been consumed. Thus, when the sensory characteristics predicted nutrients that were not delivered (as with the low energy version of the thick and creamy beverage) the mismatch between the actual and expected nutrient delivery tended to result in rebound hunger.

According to the findings of Yeomans and Chambers (Yeomans & Chambers, 2011), designing a high energy drink to taste thick and creamy could be one way to increase its satiating capacity, but their results also suggest that designing a low energy drink to taste thick and creamy may actually increase subsequent appetite. Presumably, this is because a drink that tastes thick and creamy will increase expectations of satiety, regardless of its actual energy content, which would only be determined post-consumption. However, it is not clear the extent to which the sensory characteristics of

a drink influence expectations of satiety, which is important to consider if these expectations interact with the energy content of a drink post-consumption.

To characterise the influence of sensory cues on such expectations, the present research investigated the role of satiety-relevant texture and flavour cues in the generation of satiety expectations in high and low energy beverages. In study one we assessed the extent to which participants were sensitive to small changes in beverage texture and how sensory perceptions relate to the actual viscosity of a beverage: it is important to clarify the scale of textural manipulations and how they actually translate to physical differences within a liquid product, in order to make it easier to compare beverage textural differences across studies. In study two we examined whether small manipulations of the thick texture and creamy flavour influence expectations of satiety independent of the drinks actual energy content. We assessed the role of texture and flavour as independent sensory cues and together in a combined sensory context (thick and creamy) to see how the two interact.

3.3 Method: Study one

Participants who were not sensory panellists tasted and rated 16 fruit beverages of varying thickness, manipulated by the addition of small quantities of tara gum (0.0-0.47g/100g of the drink, increasing in 0.03g increments across the 16 drinks).

Rheological measurements were taken and participants rated how thick, creamy, fruity, sticky, sweet and sour each sample was (0= not at all, 100= extremely) on two non-consecutive days. Perceived thickness was related to the viscosity at a shear rate of ≈ 50 reciprocal seconds (1/s).

3.3.1 Participants

Twenty four (12 male) participants were recruited from a volunteer database of staff and students at the University of Sussex. Participants were aged between 19-26 years ($M = 21$, $SD = 2$) and were non-obese ($M = 23 \text{ kgm}^{-2}$, $SD = 3$, where a BMI of $<18 \text{ kgm}^{-2}$ was classed as underweight, $18\text{-}25 \text{ kgm}^{-2}$ healthy, $25\text{-}30 \text{ kgm}^{-2}$ overweight and $30+ \text{ kgm}^{-2}$ obese) with a mean dietary restraint score of 6 ($SD = 4$) for females and 4 ($SD = 3$) for males, measured using the restraint scale of the Three Factor Eating Questionnaire (TFEQ; Stunkard & Messick, 1985) where possible scores range from 0 (low-restraint) to 21 (high-restraint). Male and female participants did not differ in age, restraint or BMI. They were selected to be healthy non-smokers, not currently dieting or taking prescription medication, with no eating disorders and without allergies or aversions to any of the test foods. The research was approved by the University of Sussex, Life Science Research Ethics Board, and all participants gave consent to take part in a study “Investigating the interaction between mood and taste” and received £10 payment upon completion.

3.3.2 Fruit drinks

All test beverage were designed and prepared in the Ingestive Behaviour Unit at the University of Sussex and consisted of two training drinks and 16 test drinks made from the same low-energy base (see Table 3.2). Thickness was manipulated with the addition of tara gum (Kaly's Gastronomie, France), a naturally occurring non-ionic polysaccharide commonly used commercially as a thickening agent and stabiliser. The amount of tara gum ranged from 0.0-0.47g/100g portion of the beverage base, increasing in 0.03g increments across the 16 versions. The training beverages were an

example of a ‘thin’ drink (water) and a ‘thick’ drink (the fruit drink with 0.63g/100g tara gum added). All samples were kept at 1-5°C and used within 4 days from preparation.

3.3.3 Measures

3.3.3.1 Viscosity

Rheological measurements were taken at the University of Birmingham, Department of Chemical Engineering, at 5 °C on a Bohlin Rotational Rheometer (Malvern Instruments Ltd.) using parallel-plate geometry (60 mm diameter) and a gap size of 1.0 mm. Flow behaviour was measured at shear rate 0.001-800 1/s and back down in reverse sequence for the same duration, with three repeats using a fresh sample each time. Tara gum solutions typically show non-Newtonian shear thinning behaviour (Wu, Cui, Eskin, & Goff, 2009), which means that their viscosity is not constant but is dependent on rate of flow (the shear rate) during measurement. For this reason viscosity reported in the results section is an average of the data collected at a shear rate of 52.6 1/s (referred to as ≈ 50 1/s). This was the actual shear rate the rheometer achieved when aiming for 50 1/s, which is thought to best represent in-mouth viscosity (Shama & Sherman, 1973; Sherman, 1982). While shear rates of 1000+ 1/s have been associated with in-mouth viscosity (Koliandris *et al.*, 2010), 800 1/s was the highest shear rate that could be obtained for these samples, as all the samples were relatively thin and likely to run off the rheometer plate. Parallel-plate geometry was used in order to spread the force created under shear over a wider area allowing a larger range of shear rates to be achieved accurately.

3.3.3.2 Sensory ratings

Sensory evaluations of the 16 samples were collected in the form of Visual Analogue Scale (VAS) ratings using the Sussex Ingestion Pattern Monitor (SIPM: Yeomans, 2000) running on a Dell PC using the Windows XP professional operating system. Participants were asked “How <target> is sample X?” with the targets ‘thick’, ‘sweet’, ‘sour’, ‘sticky’, ‘fruity’ and ‘creamy’. Participants were instructed to indicate the extent that each sample was <target> by dragging a marker along a 100 mm line. The scale was always anchored with the words “Not at all < target>” (0) and “Extremely <target>” (100). The presentation of each question was randomised.

3.3.4 Procedure

Test sessions were scheduled between 10.30am-12.00pm or 2.30-4.00pm Monday to Friday. In order to minimise differences in hunger, participants were instructed not to consume any food or drink (excluding water) for two hours before they were due in the laboratory. Participants were required to report if they did not fulfil these eating restrictions. Participants then underwent a brief training task to introduce them to the idea of rating a drink's 'thickness' and provide a reference standard. In the training task participants were presented with an example of the thickest and the thinnest sample they would taste throughout the session. Participants were instructed to take a small mouthful of a sample through a straw, to hold the sample in their mouth while they counted to three and then swallow. Some research suggests samples should be swallowed immediately in order to reduce dilution by saliva and temperature equilibration which can affect rheological properties of the food (Bourne, 2002). However, this technique significantly reduces the sensory exposure and oro-sensory sensitivity of the participants (De Wijk, Engelen, & Prinz, 2003). By allowing participants 3 seconds of oral exposure this allowed some degree of sensitivity whilst maintaining a level of standardisation across all samples and participants. After swallowing, participants' rated the thickness of the sample and were then prompted to take a sip of water. All participants rated the thickest sample first.

Following the training, participants were presented with a tray of 16 samples of the fruit drink and were required to taste each sample, holding the drink in the mouth for 3 seconds before swallowing. The samples were presented in 25g portions in a small clear glass with a straw and labelled A-P. After each taste participants completed a series of VAS ratings assessing the sensory characteristics of each sample. Participants were prompted to take a sip of water before moving on to the next sample. The order of presentation of the samples was randomised across all participants and sessions.

Due to the large number of samples to be tasted, participants completed the tasting session twice on two non-consecutive days in order to check that their sensory evaluations were consistent. Each test session lasted 30 minutes and participants completed the two sessions at a similar time of day. After the final session the participant's age, weight and height was recorded. Finally, participants completed questions pertaining to the purpose of the study, were debriefed, thanked and paid.

3.3.5 Data Analysis

The main outcome measures were the actual viscosity of the tara gum thickened samples measured using rheometry and the perceived sensory characteristics evaluated by volunteers. A one-factor independent sample ANOVA assessed the effect of tara gum on viscosity across the 16 test drinks.

A three-way mixed ANOVA was conducted for each sensory evaluation to assess the effect of added tara gum (16 levels) on the sensory judgements while controlling for test day (1 or 2) and gender (male or female participants). Where the assumption of sphericity was violated Greenhouse-Geisser ($\epsilon < 0.75$) or Huynh-Feldt ($\epsilon > 0.75$) corrected degrees of freedom and p -values are presented. Means and SEM are presented throughout. The relationship between viscosity at ≈ 50 1/s and each of the sensory evaluations were investigated using Pearson's correlations.

3.4 Results: Study one

3.4.1 Viscosity

Viscosity significantly increased with the addition of tara gum across the 16 samples of fruit drink ($F(15,176) = 1552.17, p < .001$; linear contrast $p < .001$), see Figure 3.1.

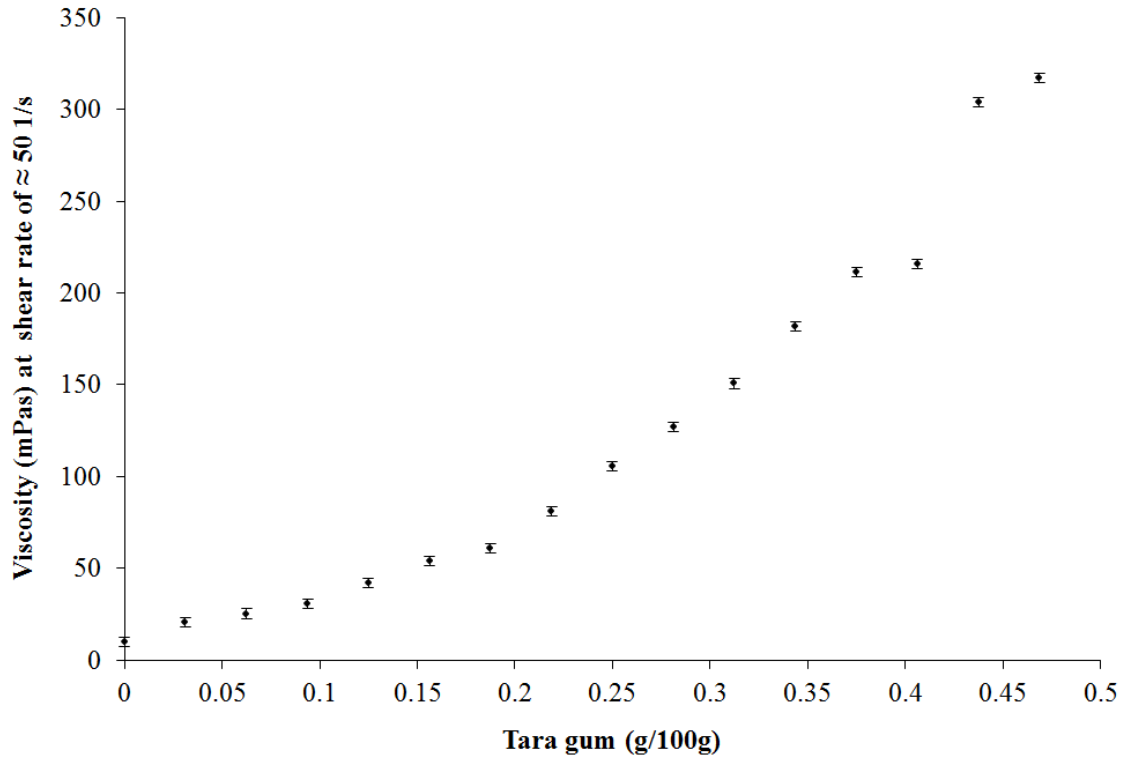


Figure 3.1 Viscosity for the 16 drink samples varying in amounts of tara gum (g/100g). Viscosity is represented in millipascal-seconds (mPa·s) at a shear rate for ≈ 50 reciprocal seconds (1/s). Error bars represent the SEM.

3.4.2 Sensory evaluations of the test drinks

The mean sensory ratings are presented in Table 3.1. Perceived thickness ($F(7, 136) = 65.38, p < .001$), creaminess ($F(5, 90) = 20.53, p < .001$) and stickiness ($F(6, 104) = 11.96, p < .001$) increased with the amount of tara gum in each sample (linear contrast $p < .001$ for all) but rated sweetness, sourness and fruitiness did not differ across samples ($p > .05$ for all). There was no effect of gender or test day on any of the ratings (all $p > .05$) except for sourness where there was a small but significant gender * day * sensory interaction ($F(8, 169) = 2.02, p = .047$): some of the 16 samples were rated as slightly more or less sour depending on the gender of the participant and the day the rating was made, although there was no clear pattern to this interaction, which is likely to be a spurious finding given the large number of potential interactions.

3.4.3 Relating sensory characteristics to viscosity

Table 3.1 details the correlations between the viscosity of each sample and their perceived sensory characteristics. Perceived thickness was strongly related to viscosity: as the viscosity of each sample increased so did perceived thickness. Creaminess and stickiness ratings also increased with viscosity. There was a small but significant positive relationship between rated fruitiness and viscosity indicating that there was a small increase in perceived fruitiness in the thicker samples, which was not picked up in the ANOVA analysis on the fruity ratings. There was no relationship between the viscosity of the sample and perceived sweetness or sourness.

3.4.4 Summary

The results from study one indicate that participants, who are not trained sensory panellists, were able to perceive subtle differences in drink texture, and these differences were closely related to actual viscosity. This is in line with previous evidence that suggests viscosity at a shear rate of 50 1/s relates to perceived thickness (Shama & Sherman, 1973; Sherman, 1982). Small incremental increases in tara gum across the 16 drink samples produced measurable increases in viscosity (10-317 mPa·s, ranging from a fluid juice texture to a thicker drinkable-yogurt texture, all consumed through a regular straw) and the participants perceived these subtle changes, although probably not at the level of every incremental increase. This sensitivity to subtle differences in viscosity is not surprising because texture is likely to be one sensory characteristic of food that reliably predicts the presence of nutrients, such as fat (Drewnowski, 1990).

Table 3.1 Sensory ratings for each beverage sample used in study one and their association with measured viscosity.

	Beverage sample (tara gum g/100g)																Persons <i>r</i>
	0	0.03	0.06	0.09	0.13	0.16	0.19	0.22	0.25	0.28	0.31	0.34	0.38	0.41	0.44	0.47	
Thickness	11 ± 2	16 ± 3	24 ± 4	27 ± 4	30 ± 3	31 ± 4	41 ± 4	41 ± 4	57 ± 4	55 ± 3	64 ± 4	64 ± 4	73 ± 3	82 ± 2	83 ± 2	85 ± 2	0.92 **
Creaminess	25 ± 3	32 ± 5	41 ± 4	42 ± 4	35 ± 3	48 ± 3	52 ± 4	51 ± 3	56 ± 4	60 ± 3	63 ± 3	60 ± 3	71 ± 3	70 ± 3	73 ± 3	77 ± 3	0.92 **
Stickiness	21 ± 4	25 ± 4	25 ± 3	27 ± 4	31 ± 4	30 ± 4	35 ± 3	34 ± 4	36 ± 4	41 ± 5	48 ± 4	45 ± 5	52 ± 5	54 ± 5	51 ± 5	54 ± 5	0.95 **
Sweetness	59 ± 4	57 ± 4	58 ± 4	62 ± 4	60 ± 4	59 ± 4	61 ± 4	59 ± 3	65 ± 3	62 ± 3	60 ± 4	61 ± 3	61 ± 4	61 ± 4	59 ± 4	62 ± 4	0.29 <i>ns</i>
Sourness	35 ± 5	39 ± 5	42 ± 4	37 ± 5	41 ± 4	36 ± 4	41 ± 5	44 ± 5	37 ± 4	38 ± 4	37 ± 5	38 ± 4	48 ± 5	36 ± 5	37 ± 4	42 ± 5	0.13 <i>ns</i>
Fruitiness	55 ± 4	60 ± 3	58 ± 4	59 ± 4	64 ± 3	63 ± 3	60 ± 4	60 ± 4	64 ± 3	67 ± 3	66 ± 2	62 ± 3	64 ± 3	64 ± 3	65 ± 4	61 ± 4	0.50 *

Numbers represent the mean VAS rating (0 = not at all, 100 = extremely) and associated SEM for each of the sensory evaluations across the 16 fruit beverages varying in the amount of tara gum/100g. Pearson's *r* shows the relationship between each sensory characteristic and the drinks measured viscosity.

* Correlation coefficient is significant at $p < .05$

** Correlation coefficient is significant at $p < .001$

3.5 Method: Study two

New participants, who were not trained sensory panellists, evaluated the sensory and hedonic characteristics of eight versions of a fruit drink, varying in thickness (thin vs. thick), creamy flavour (low-creamy vs. high-creamy) and energy content (higher-energy vs. lower-energy). The participants also rated how filling they expected each drink to be (0 = not at all, 100 = extremely) and its expected satiety. In the expected satiety measure participants indicated the extent to which they expected each drink to suppress hunger until the next meal by selecting a portion of pasta and sauce that they thought would have the same effect on their hunger. Selecting a larger portion of pasta and sauce (kcal) indicated that the drink was expected to be more satiating.

3.5.1 Participants

Twenty-five participants (9 male) were staff and students at the University of Sussex, recruited from the same volunteer database as study one and conformed to the same selection criteria but had not taken part in the study. Participants were aged 19-26 ($M = 21$, $SD = 3$), non-obese (BMI: $M = 23 \text{ kgm}^{-2}$, $SD = 3$) with an average TFEQ restraint score of 6 ($SD = 5$) for males and 6 ($SD = 4$) for females and these characteristics were similar between male and females. The study was approved by the University of Sussex, Life Science Research Ethics Board, and all participants gave written consent to take part in a study “Investigating the interaction between mood and taste” and received £6 payment upon completion.

3.5.2 Test drinks

The fruit drinks were designed with four satiety-relevant sensory conditions varying in thickness (thin vs. thick) and creamy flavour (low-creamy vs. high-creamy) with high-energy (HE) and low-energy (LE) versions for each. Table 2.3 contains the ingredients and basic nutritional composition of the LE and HE fruit drink bases. Creamy flavour was enhanced by the addition of vanilla extract (Nielsen-Massey, NL: 19 drops/100g) and milk caramel flavouring (Synrise, DE: 0.16g/100g) and thickness was increased by manipulating the amount of tara gum (g/100g) in each drink (thin/low-creamy LE: 0.09g; thin/low-creamy HE: 0g; thin/high-creamy LE: 0.09g; thin/high-creamy HE: 0g; thick/low-creamy LE: 0.38g; thick/low-creamy HE: 0.31g; thick/high-creamy LE 0.38g; thick/high-creamy HE: 0.31g). More tara gum was added to the LE versions of the

drinks in order to account for the small increase in thickness caused by the addition of maltodextrin to the HE versions, and rheological measurements were relatively well matched across the high- and low-energy drinks in the thin (LE = 21 mPa·s, HE = 31 mPa·s) and thick (LE = 222 mPa·s, HE = 184 mPa·s) contexts. The thick drinks were similar in viscosity to the sample containing 0.34-0.40g/100g tara gum in study one, and the thin drinks were similar in viscosity to the sample containing 0.03-0.09g/100g in study one. Colour was matched between all the drink samples by the addition of small quantities of natural food colouring (see Table 3.2).

Table 3.2 Ingredients and basic nutritional composition per 100g of the high- and low-energy fruit drink base.

	Low-energy*		High-energy*	
	weight (g)	kcal	weight (g)	kcal
Peach/Passionfruit juice ^a	31.3	14.4	31.3	14.4
Peach squash ^b	10.9	1.2	10.9	1.2
0.1 % fat Fromage frais ^a	17.2	8.6	9.4	4.7
Water	40.6	0	31.2	0
Maltodextrin ^c	0	0	17.2	65.3
Aspartame ^d	0.009	0	0	0
<i>Yellow colour^e</i>	<i>3 drops</i>	<i>0</i>	<i>0</i>	<i>0</i>
<i>Red colour^e</i>	<i>1 drop</i>	<i>0</i>	<i>0</i>	<i>0</i>
Total	100g	24.2	100g	85.6

*Low energy drinks were used in study one and both high and low energy drinks were used in study two.

a Sainsbury's Ltd., London, UK.

b Robinsons, Britvic, UK.

c Cargill, UK.

d Aspartame Powder, Ajinomoto Sweetners Europe.

e Silverspoon, British Sugar, UK.

3.5.3 Measures

3.5.3.1 Hunger, fullness and thirst

VAS ratings of appetite were collected using SIPM and had the same format as the sensory ratings in study one. Participants rated how 'hungry', 'full' and 'thirsty' they

were from not at all (0) to extremely (100) and these ratings were embedded amongst other distracter “Mood” questions: calm, happy, clearheaded, anxious, nauseous, headachy, tired, energetic, and alert. Only the appetite questions were analysed and all questions were presented in a randomised order.

3.5.3.2 Sensory evaluations and filling rating

Participants also made VAS ratings of how ‘sweet’, ‘thick’, ‘creamy’, ‘pleasant’, ‘sticky’ and ‘fruity’ the drinks were, as well as rating the extent to which each sample was expected to be filling. All ratings were from ‘not at all’ (0) to ‘extremely’ (100) and were presented in a random order.

3.5.3.3 Expected satiety

The measurement of expected satiety was based on a computer-based methodology developed by Brunstrom and colleagues (Brunstrom *et al.*, 2008). The program was written in Visual Basic software displayed on a Dell laptop computer running Windows 7. Participants were presented with the set of eight drink samples and a 320g portion of the drink base in a clear plastic bottle with a fastened lid, representing a standard drink serving. Participants were prompted by on screen instructions to “Take a sip of sample X” using the straw provided. Then, they were presented with an image of pasta and tomato sauce and instructed to “Imagine you are going to consume the whole bottle of Sample X for lunch. How much pasta would you need to eat to match the effect of Sample X on your hunger?”. Participants used the left and right arrow keys on the keyboard to move through images and increase/decrease the amount of pasta and sauce displayed. There were 101 images of pasta and sauce in total (‘Egg penne pasta’: Sainsburys Ltd, London, UK; ‘Sundried stir-in tomato sauce’) ranging from 10 kcal in image 0 to 1000 kcal in image 100. Portion sizes increased across images in logarithmic steps, such that images 0, 20, 40, 60, 80, 100 showed 10 kcal, 25 kcal, 63 kcal, 159 kcal, 398 kcal, and 1000 kcal respectively. Participants selected enter when they had selected their required portion size. All images were taken by a high-resolution digital camera mounted above a 255-mm diameter white plate and effort was made to maintain consistency of lighting and camera angle across each photograph. All participants confirmed that they had eaten pasta and tomato sauce before.

3.5.4 Procedure

Participants completed one test session that lasted approximately 45 minutes and was scheduled on a weekday between 10.30-12.30pm or 2.30-4.30pm. As in study one, participants were required to consume only water for 2 hours prior to attending the lab and report any lack of compliance to these restrictions. Participants completed the session in an air-conditioned testing cubicle with a PC computer.

To begin, participants rated their subjective appetite disguised as a series of “Mood questions”. They were then presented with 25g portions of the eight test drinks, each in a small clear glass labelled A-H, and were informed that they would taste each sample twice using the straws provided. Participants first tasted each sample to make the sensory VAS ratings and to rate how filling they expected it to be, and then tasted the samples for a second time to complete the expected satiety task. Half of the participants completed the two tasks in the reverse order and all were provided with water throughout. Once the tastings were finished participants completed a final set of appetite ratings, and then were debriefed, thanked and received their compensatory payment.

3.5.5 Data analysis

Appetite ratings were taken before and after the tasks as a difference in subjective appetite prior to the test may have influenced task performance. A one-factor mixed ANOVA assessed the effect of time (*pre-test* vs. *post-test*) on the three measures of appetite, and a series of Pearson’s correlations were used to assess the relationship between pre-test hunger, fullness and thirst to the anticipated fullness and expected satiety of the drinks.

A series of three-way mixed ANOVAs and Bonferroni adjusted comparisons, contrasted the effect of drink thickness (*thin* vs. *thick*), creamy flavour (*low-creamy* vs. *high-creamy*) and energy context (LE vs. HE) on each of the expectations (anticipated fullness and expected satiety) and the sensory and hedonic ratings. The expected satiety scores represent the quantity (in kcal) of pasta and tomato sauce presented in the image selected by the participants. These data were log transformed in order to improve normality for the analysis. However, the descriptive data and mean values were presented in kcal in order to aid interpretation. It was anticipated that the expectation

that a drink would be filling would be strongly related to its expected satiety, and this was tested using a series of Pearson's correlations to assess the relationship between these two expectations across the eight test drinks.

Initially these analyses also included task order (VAS ratings/expected satiety vs. expected satiety/VAS ratings) as a control factor. However, there was no significant effect or interactions with this task order and it was removed from the final analysis. Twenty-five participants took part in the study but the data from three participants were removed as their expectation values (filling rating and/or expected satiety) were more than 2 standard deviations from the mean. Consequently, data from 22 participants were included, leaving 16 females and just six males in the final analysis. For this reason gender was not included as a factor due to an inadequate number of males. Means and SEM are presented throughout.

3.6 Results: Study two

3.6.1 Filling ratings

The ANOVA revealed a significant effect of both thick texture ($F(1,21)=98.98, p < .001$) and creamy flavour ($F(1,21)=20.89, p < .001$) on the extent to which the drinks were expected to be filling, independent of the drinks energy content (for all interactions with energy all $p > .05$), see Figure 3.2. Averaged across energy versions, the thick drinks ($M = 65 \pm 2$) were expected to be more filling than the thin drinks ($M = 42 \pm 2$) and the high-creamy versions of the drink ($M = 57 \pm 2$) were expected to be more filling than the low-creamy versions ($M = 49 \pm 2$). There was no thick * creamy interaction ($F(1,21) = 0.62, p = .440$): increasing drink thickness increased the filling rating, which was enhanced by the addition of creamy flavour similarly across the thick and thin versions (see Figure 3.2). There was no overall effect of the drinks' energy content on ratings of how filling the drink was expected to be ($F(1,21) = 3.16, p = .090$).

3.6.2 Expected satiety

There was also a significant effect of drink thickness on expected satiety judgements ($F(1,21) = 63.27, p < .001$): the thick drinks had a greater expected satiety than the thin drinks, see Figure 3.3. However, the creamy versions of the drinks were not expected to suppress hunger any more than their low-creamy counterpart ($F(1,21) = 0.60, p = .448$) and there was no thick * creamy interaction ($F(1,21) = 2.60, p = .122$). There was no main effect of the drinks energy content on expected satiety ($F(1,21) = 0.52, p = .488$) but the analysis did reveal a significant thick * energy interaction ($F(1,21)=12.73, p = .002$): closer inspection revealed that the HE thin drinks ($M = 128 \pm 16$) had a lower expected satiety than the LE thin drinks ($M = 148 \pm 17$), whereas the HE thick drinks ($M = 269 \pm 34$) and LE thick drinks ($M = 266 \pm 34$) were similarly expected to be the most satiating. However, Bonferroni adjusted comparisons revealed no significant difference in expected satiety between the LE and HE thin beverages ($p = .416$) or the LE and HE thick drinks ($p = .999$).

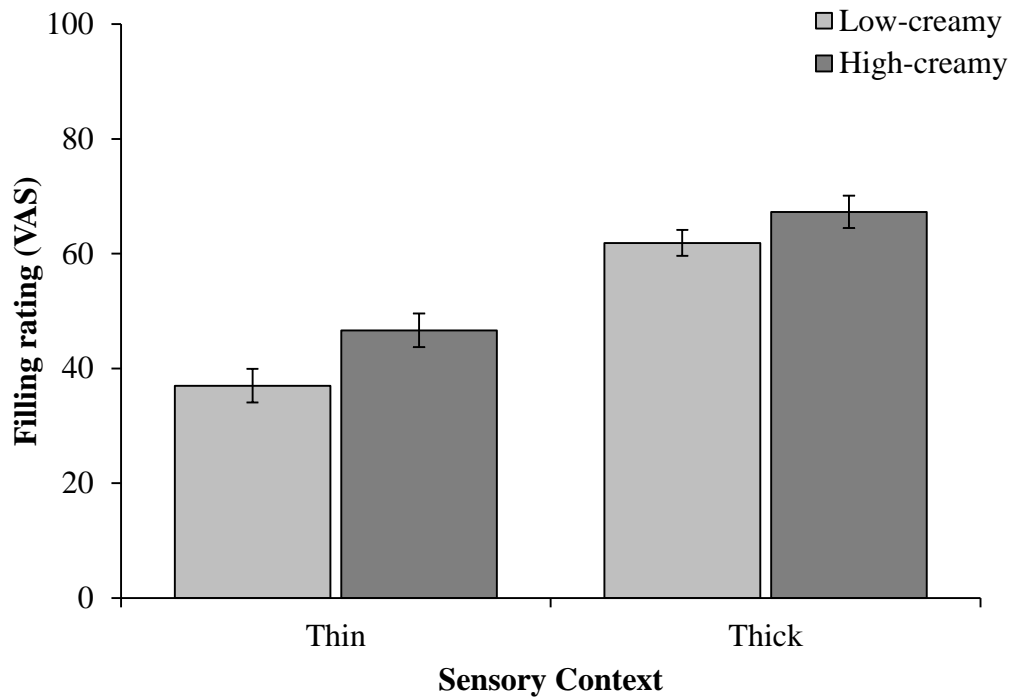


Figure 3.2 Filling VAS ratings (0 = not at all, 100 = extremely) \pm SEM for the drinks, collapsed across drink energy content. The thick drinks were expected to be more filling than the thin drinks ($p < .001$). The addition of creamy flavour increased this expectation as the creamy drinks were rated as more filling than the low-creamy versions ($p < .001$).

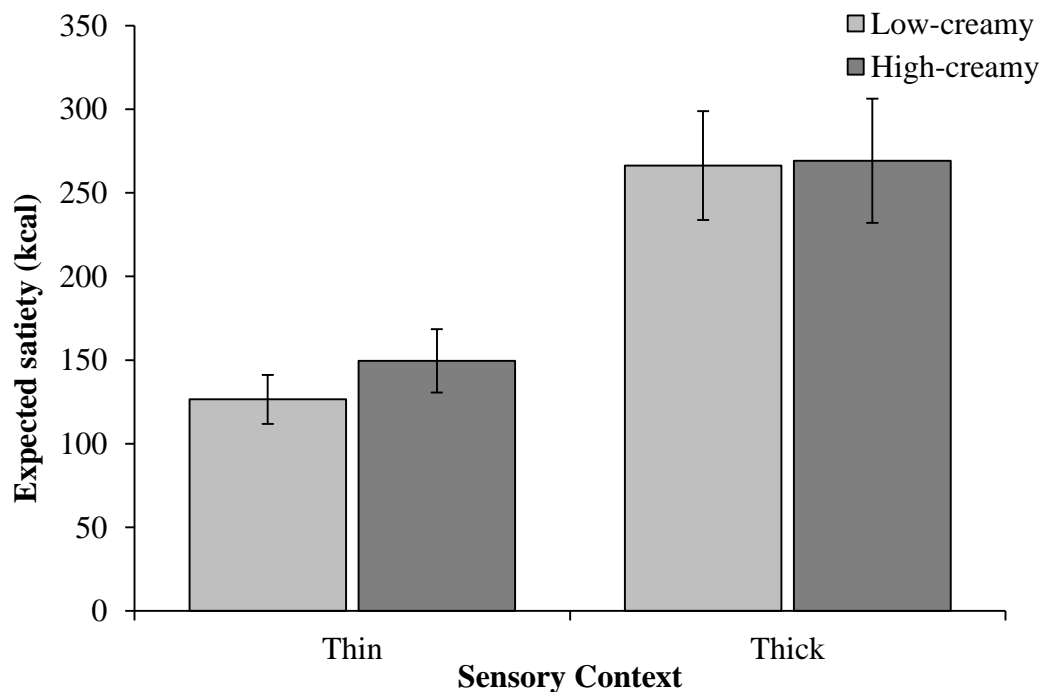


Figure 3.3 The mean portion of pasta and tomato sauce selected in the expected satiety task (kcal \pm SEM), collapsed across drink energy content. The thick drinks had a larger expected satiety than the thin drinks ($p < .001$) and the addition of creamy flavour to the high-creamy drinks did not increase this expectation ($p > .05$).

3.6.3 Relating the filling rating to expected satiety

We anticipated that the two judgements measuring the extent to which the drinks were expected to be filling (VAS ratings) and to suppress hunger (expected satiety) would be related. Unexpectedly, Pearson's correlation indicated that for each of the eight drinks varying in thickness, creamy flavour and energy content, there was little relationship between the expectation that it would be filling and its expected satiety. Across the eight drinks the two expectations were only significantly related for two of the drinks (for all others $p > .05$). For the high energy thick and creamy drink the more filling it was expected to be the greater its expected satiety ($r = 0.53, p = .011$), whereas the more filling the low energy thick and low-creamy drink was expected to be, the lower its expected satiety ($r = -0.57, p = .005$). This shows little relationship between the two expectations.

3.6.4 Sensory and hedonic evaluations of the drinks

ANOVA analyses revealed that the drinks differed on several sensory attributes (see Table 3.2). The thick drinks were rated as more thick ($F(1,21) = 170.79, p < .001$), creamy ($F(1,21) = 52.48, p < .001$) and sticky ($F(1,21) = 40.96, p < .001$) than the thin drinks, and less fruity ($F(1,21) = 18.19, p < .001$). Drink texture did not affect sweetness ratings. The creamy drinks were rated as creamier ($F(1,21) = 17.74, p < .001$), thicker ($F(1,21) = 13.47, p = .001$) and slightly sweeter ($F(1,21) = 6.40, p = .020$) than the low-creamy drinks. The addition of creamy flavour did not affect the perceived fruitiness or stickiness of the drinks. All the drinks were rated as similarly pleasant regardless of thick texture, creamy flavour or energy content (all main effects and interactions $p > .05$). There was no thick * creamy interactions for any of the sensory characteristics (all $p > .05$). Overall, there was no main effect of drink energy on thick, creamy, sticky, fruity, sweet and pleasantness ratings for each of the drinks (all $p > .05$). However, there was a small but significant thick * energy interaction for the creamy ratings ($F(1,21) = 4.77, p = .040$). Bonferroni adjusted comparisons revealed that the HE thick drinks ($M = 67 \pm 3$) were rated as similarly creamy to the LE thick drinks ($M = 72 \pm 2; p = .350$), but the HE thin drinks ($M = 35 \pm 4$) were rated as less creamy than the LE thin drinks ($M = 51 \pm 3; p = .003$).

Table 3.2 Sensory evaluations of drinks used in study two across each sensory context.

	Thin		Thick	
	Low-creamy	High-creamy	Low-creamy	High-creamy
Creamy	35 ± 4 ^{ac}	51 ± 4 ^{ad}	67 ± 3 ^{bc}	72 ± 2 ^{bd}
Fruity	63 ± 4 ^{ac}	66 ± 3 ^{ad}	50 ± 4 ^{bc}	54 ± 4 ^{bd}
Pleasant	58 ± 4 ^a	63 ± 3 ^a	56 ± 4 ^a	57 ± 6 ^a
Sticky	33 ± 4 ^a	34 ± 3 ^a	52 ± 4 ^b	56 ± 4 ^b
Sweet	58 ± 3 ^a	65 ± 3 ^b	55 ± 3 ^a	61 ± 3 ^b
Thick	26 ± 3 ^{ac}	37 ± 2 ^{ad}	68 ± 3 ^{bc}	73 ± 3 ^{bd}

Evaluations are collapsed across high energy and low energy versions for the eight drinks and represent the mean VAS rating (0 = not at all, 100 = extremely) and associated \pm SEM for the drinks in the four sensory contexts, varying in thickness and creamy flavour. Within the same rating, values marked with different letters were statistically different ($p < 0.05$), whereas those with the same letters were statistically similar ($p > 0.05$)

3.6.5 Hunger, fullness and thirst pre- and post- test

Rated hunger decreased ($F(1,21) = 13.91, p = .001$) and rated fullness increased ($F(1,21) = 110.70, p < .001$) from pre- to post-test. There was no difference in thirst from the beginning to the end of the session. Pre-test hunger ratings were not related to the filling and expected satiety judgements across the eight drinks ($r = -0.40$ - $0.06, p > .05$).

3.6.6 Summary

The results from study two indicate that sensory characteristics can influence a beverage's expected satiating effect, independent of its actual energy content. Both creamy flavour and thick texture enhanced the expectation that a drink would be filling, but thick texture influenced this expectation more so than creamy flavour. The addition of a thicker texture, but not creamy flavourings, increased the expectation that the drink would suppress hunger over time. Interestingly, for each drink participant's expectations that a beverage would be filling were generally not related its expected satiety value, suggesting that participants could have been using different strategies to make these two judgements.

3.7 Discussion

The results from the present studies suggest that consumers are sensitive to subtle changes in the sensory characteristics of a drink and that thick texture and creamy flavour can be manipulated to enhance satiety expectations, but that their contributions are not equal. Our findings also indicate that beverages can differ in the extent to which they are expected to be satiating, regardless of the actual calories they contain. This is important because at least in the short term, manipulating the expected and not the actual calories of a product has been shown to influence subjective appetite (Brunstrom *et al.*, 2011), subsequent ghrelin response (Crum *et al.*, 2011) and intake at a later meal (Shide & Rolls, 1995; Wooley *et al.*, 1972). Although the present research did not measure the actual satiating effect of the test beverages, Yeomans and Chambers (Yeomans & Chambers, 2011) found that thick and creamy sensory characteristics enhance the satiety value of a drink, but only when those characteristics correctly predicted the delivery of nutrients. Taken together, this suggests that both a high and low energy drink that is made to taste thicker will be expected to be more satiating, but this expectation may have different effects on satiety depending on the actual energy content that is delivered post-consumption.

So why then should thickness be a good predictor of satiety in a beverage? For one, human adults have already had a wealth of experience with foods across their lifetime and often liquids that are more viscous do have more calories (such as honey vs. water). For example, variation in the energy density of breast milk has been shown to correlate with viscosity (Picciano, 1998) and this variability might lead to learnt associations between perceived thickness and satiety (Davidson & Swithers, 2004). The natural flavour of milk would be expected to be part of this association but one possibility is that increased oral exposure experienced with more viscous liquids makes it easier to associate the sensory characteristics of a thicker beverage, such as flavour, with its post-ingestive consequences (de Graaf & Kok, 2010; Mars *et al.*, 2009); creamy flavour alone is not likely to increase oral exposure which may make it a less effective cue for learning when it is independent of an increase in viscosity.

In study two the addition of creamy flavour did not impact satiety expectations as much as a thick texture so it is possible that creamy flavour is not a good predictor of a foods

caloric value. Reduced fat and ‘diet’ food products, such as low fat yogurts, are often produced to have the same ‘creamy’ flavour as the full calorie versions to increase satisfaction and palatability. An inconsistent relationship between the sensory characteristics of a food and its energetic value may weaken the associations formed between them (Rudenga & Small, 2012; Swithers *et al.*, 2006; Swithers, Ogden, & Davidson, 2011). We could have taken a measure of participants reported previous experience with these types of diet food products to see if this affected the ability of the creamy flavour cue to generate satiety expectations. However, our results consistently indicated that as the viscosity of a drink increased it was perceived to be thicker but also creamier and stickier. It seems likely that rating the drinks as ‘creamy’ is just not a sensitive enough measure for the general consumer, confounded by the complex sensory profile of creamy dairy products that is based on a combination of flavour and texture attributes (Kirkmeyer & Tepper, 2005). Furthermore, the creamy drinks were not only rated as creamier than the low-creamy drinks, but also thicker, so we cannot rule out the possibility that the creamy drinks were instead expected to be more filling based on their enhanced perceived thickness.

The complexity of the creamy sensory characteristic may have contributed to any discrepancies between the high and low-energy versions of the drinks. Energy content was not predicted to influence satiety expectations as the high and low energy versions of the drinks were designed to be matched in terms of perceived flavour and texture and the drink samples were only tasted and not consumed in full portions. However, there was evidence in the expected satiety measure that the low energy thin drinks were expected to be more satiating than the high-energy thin drinks. This difference maps on to the finding that the low energy thin drinks were also rated as creamier than the high energy thin drinks, possibly because overall the low energy drinks were slightly more viscous and had slightly more fromage frais in than the high energy drinks (see study two ‘test drinks’ in the method section for viscosities and ingredients), and this difference may have been more noticeable in the thin versions. This highlights just how important it is for satiety studies to match high and low energy versions of test food for characteristics such as thickness and creaminess.

Within a liquid context thicker drinks have been shown to suppress hunger to a greater extent than a calorie matched thin version (Mattes & Rothacker, 2001; Zijlstra *et al.*,

2009b) and this could be because the thicker drinks were expected to be more satiating. However, an alternative explanation for this could be that the thickener used to manipulate viscosity had a post-ingestive effect. If this is the case the effect of increased satiety expectations generated by these texture cues may be redundant. Water soluble polysaccharides used to increase liquid viscosity, such as tara gum and guar gum, also increase its dietary fibre content and the addition of a small quantity of fibre (0.82-1.5g per 100g of a drink) has been shown to increase the short term satiety value of a beverage, with delayed gastric emptying implicated as a possible mechanism (Ibrugger, Kristensen, Mikkelsen, & Astrup, 2012; Marciani *et al.*, 2000). However, what was not considered in these studies is that the addition of fibre also increases oral viscosity and the quantities of fibre used was larger than those used to manipulate thickness in the current study. One possibility is that expectations of satiety generated by a thicker liquid actually contribute to the increased satiety value of these fibre-enhanced beverages. Expectations generated by the oral viscosity and anticipated gastric viscosity of a solid and liquid food have recently been shown to influence subjective appetite, intake and gastrointestinal function (Cassady *et al.*, 2012), highlighting the potential for satiety-relevant expectations to influence the post-ingestive development of satiety. It is unlikely that small differences in the viscosity of a beverage would persist post-ingestion due to the influence of gastric dilution (Marciani *et al.*, 2000), instead beliefs about the post-ingestive effects of the beverage may be important.

An unexpected outcome of study two was the lack of relationship between the expectation that a drink will be filling and its expected satiety. There is evidence to suggest that people differ in the sensory information that they use to guide food intake (Shaffer & Tepper, 1994) and one possibility is that our participants were using different strategies to make these two judgements. However, the way in which individuals differentially use flavour and texture cues to generate satiety expectations is not clear. In the present research it appears that both textural and flavour cues contributed to the extent to which the drinks were expected to be filling, whereas only drink thickness influenced expected satiety. In our measure of expected satiety participants compared the anticipated satiating effect of a fruit drink to that of pasta and tomato sauce, whereas the expectation that the drink will be filling was measured on a rating scale. One possibility is that when the participants imagined the expected satiety

of each drink sample in comparison to pasta and sauce, texture was a more relevant cue for satiety. Creamy flavour may have been overlooked because if it is not a relevant sensory characteristic of pasta and sauce. Furthermore, participants may have found it harder to imagine a suppression of hunger in the expected satiety tasks compared to an increase in fullness in the rating measure. In future it would be useful to measure the method of adjustments comparisons and VAS ratings for both types of expectations generated by sensory cues, to see how they compare.

Finally, it is important to note that the current research had a repeated measures design and all the participants tasted each of the drinks during the session. It is possible that the influence of the drinks sensory characteristics on satiety expectations was more pronounced due to contrast effects and from this study it is not clear how these subtle sensory differences would influence expectations in a single drink product day to day when not tasted alongside a similar product.

3.7.1 Conclusion

Overall, the present research indicates that people are sensitive to subtle changes in the sensory quality of a drink and these characteristics can increase the expectation that a beverage will be filling (anticipated satiation) and suppress hunger over time (expected satiety). It appears that thick texture, rather than creamy flavour had the biggest influence on satiety expectations and this was independent of the drinks actual energy content. Therefore enhancing the texture of high-energy beverages to be more satiety relevant may be one way to increase their weak satiating capacity. These findings also highlight the importance of matching sensory characteristics, such as texture, in studies that manipulate the energy density of foods or the sensory context of energy-matched products.

3.7.3 Acknowledgements

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3.7.4 Authors contributions

MRY, LC and KMc designed the study. KMc prepared the study materials, collected and analysed the data and viscometry, and drafted the manuscript. JMB programmed the expected satiety task using materials developed by KMc. All authors approved the final manuscript. .

4. Paper three

Does modifying the thick texture and creamy flavour of a drink change portion size selection and intake?

Keri McCrickerd^{1*}, Lucy Chambers¹ and Martin R. Yeomans¹

¹ *School of Psychology, University of Sussex, Brighton, BN1 9QH, UK*

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4.1 Abstract

Previous research indicates that a beverage's sensory characteristics can influence appetite regulation. Enhancing the thick and creamy sensory characteristics of a drink generated expectations of satiety and improved its actual satiating effects. Expectations about food also play an important role in decisions about intake, in which case enhancing the thick and creamy characteristics of a beverage might also result in smaller portion size selection. In the current study forty-eight participants (24 female) completed four test days where they came into the laboratory for a fixed-portion breakfast, returning two hours later for a mid-morning beverage, which they could serve themselves and consume as much as they liked. Over the test days, participants consumed an iso-energetic beverage in four sensory contexts: thin and low-creamy; thin and high-creamy; thick and low-creamy; thick and high-creamy. Results indicated that participants consumed less of the thicker beverages, but that this was only true of the female participants; male participants consumed the same amount of the four beverages, regardless of sensory context. The addition of creamy flavour did not affect intake but the thicker drinks were associated with an increase in *perceived* creaminess. Despite differences in intake, hunger and fullness ratings did not differ across male and female participants and were not affected by the beverage's sensory characteristics. The vast majority of participants consumed all of the beverage they served themselves, indicating that differences in intake reflected portion size decisions. These findings suggest women will select smaller portions of a beverage when its sensory characteristics indicate that it will be satiating.

4.2 Introduction

Caloric beverage are reported to have a weaker satiety value than energy-matched ‘foods’, such as solid and semi-solid items and liquid soups (Hulshof *et al.*, 1993; Mattes, 2005, 2006b; Mourao *et al.*, 2007; Tournier & Louis-Sylvestre, 1991). A food’s oro-sensory characteristics are important for the development of satiety (Cecil *et al.*, 1998, 1999), triggering learned salivatory and gastrointestinal cephalic phase responses which are thought to aid the digestion of nutrients and enhance the experience of satiety (Mattes, 1997, 2006c; Woods, 1991). Evidence that energy consumed in liquid form elicits a weak cephalic phase response (Teff, 2010; Teff *et al.*, 1995) suggests that the strength of associations formed between a drink’s sensory characteristics and its post-ingestive effect is weak; possibly because they are consumed fast, and this reduced oral exposure time may limit the strength of its oro-sensory signal and subsequent learning (Mars *et al.*, 2009). As a result, energy consumed as a drink may not be *expected* to be satiating, and the potential for these expectations to influence decisions about consumption is the focus of the present study.

Recent research from our laboratory supports the idea that the sensory characteristics of a drink can limit its satiety value: drinks varying in thick texture and creamy flavour were expected to have different satiating effects (McCrickerd *et al.*, 2012). The thicker drinks were expected to be more filling (expected satiation) and to suppress hunger to a greater extent (expected satiety) than thin versions, regardless of their actual energy content. The addition of creamy flavours had less of an effect on expectations of satiation and satiety, but *perceived* creaminess was important and this was associated with the beverage’s thicker texture. Indeed, perceived creaminess has both textural (thickness and smoothness) and flavour (dairy, vanilla and sweetness) attributes (De Wijk *et al.*, 2006; Kirkmeyer & Tepper, 2005) typically associated with nutrients. Moreover, energy compensation following a beverage preload was improved by modifying its creamy texture and flavour to better signify the presence of the nutrients (Bertenshaw *et al.*, 2013; Yeomans & Chambers, 2011). This fits with the Satiety Cascade Model (Blundell *et al.*, 1987), which proposes that early cognitive and sensory information is integrated with later post-ingestive and post-absorptive signals to suppress appetite after an eating episode. However, the Satiety Cascade also predicts that sensory characteristics and beliefs about the satiety value of food strongly influence

satiation (the process of ending a meal or eating episode) and therefore the amount people eat (Blundell *et al.*, 2010; Blundell *et al.*, 1987; Brunstrom, 2011). So if a person expects a beverage to be filling because it is thick and creamy, as our previous research suggests, they may select a smaller portion size and/or consume less of that drink.

So far research has demonstrated that increasing the viscosity of a liquid did result in decreased *ad libitum* consumption, but whether this reduction is based on the belief that a thicker product would be more filling is less clear. Hogenkamp, Mars, Stafleu and de Graaf (2012b) provided participants with 1000g portions of a custard product as either a lemon-flavoured liquid or a meringue-flavoured and “caramel” coloured semi-solid, both to be consumed from a large bowl with a spoon. Participants expected the thicker custard to be most filling and consumed approximately 30% less of that custard compared to the thin version. However, because the colour and flavour were not matched across the thick and thin versions, the extent to which differences in intake can be attributed to viscosity alone is limited; these other cues may have influenced beliefs and intake. In a drink context, Zijlstra, Mars, de Wijk, Westterp-Plantenga and de Graaf (2008) found similar reductions in intake of an iso-energetic semi-solid chocolate milk compared to a less viscous liquid version, which were presented in 1.5 litre opaque cartons and frequently replaced so the serving could not be finished. The researchers suggest this was due to a difference in eating rate between the products because when eating rate was standardised participants consumed a similar amount of the thick and thin versions. Indeed, *ad libitum* consumption from a ‘bottomless’ portion is a good measure of satiation, but is likely to emphasise factors such as eating rate, stomach distension and appetitive sensations, whilst limiting the opportunity for participants to plan, see and adjust the amount of food they consume based on visual and olfactory cues, and pre-existing expectations about its satiating effects. Beliefs and expectations about the satiating value of foods are an important determinant of self-selected portion size (Wilkinson *et al.*, 2012) and portion size decisions are a regular feature of everyday eating behaviour, alongside consuming all of the food selected (Fay *et al.*, 2011a).

The present study aimed to extend the previous findings that thick texture and creamy flavours can modify expectations and enhance satiety, by determining whether such sensory manipulations also influence actual self-selected intake of a drink and assessing

the relative contribution of satiety-relevant texture and flavour cues. Participants were able to select the amount of a drink to consume across four different sensory contexts identical to those used in our previous research (McCrickerd *et al.*, 2012): thin and low-creamy flavour; thin and high-creamy flavour; thick and low-creamy flavour; thick and high-creamy flavour. It was predicted that participants would consume less of the thicker drinks than the thinner ones, as thick texture generated strong expectations of satiety, and that the addition of a creamy flavours would have more subtle effects on intake. A secondary prediction was that the self-served drink would be consumed in its entirety.

4.3 Method

4.3.1 Participants

Forty-eight participants (24 female) completed the study “investigating the effect of breakfast on mood and alertness”. Participants were recruited from a volunteer database of staff and students at the University of Sussex. Participants were selected to be non-smokers, not currently dieting or diagnosed with an eating disorder, without allergies or aversions to any of the test food ingredients and not taking prescription medication. On average, participants were 21 years (range = 18-52 years, $SD = 5$), not obese (mean BMI = 23 kg/m², range = 18-30 kg/m², $SD = 3$, where <18 kgm⁻² is classed as underweight, 18-25 kgm⁻² healthy, 25-30 kgm⁻² overweight and 30+ kgm⁻² obese) and mean dietary restraint score of 7 for males (range = 1-16, $SD = 4$) and 7 for females (range = 1-15, $SD = 4$), measured using the Three Factor Eating Questionnaire (TFEQ: Stunkard & Messick, 1985), where possible scores range from 0 (low-restraint) of the maximum 21 (high-restraint). Male and female participants did not differ in age, restraint and BMI. The research was approved by the University of Sussex Life Science Research Ethics Board.

4.3.2 Design

A three-factor mixed design was used to assess the effect of drink texture (thin vs. thick) and the addition of creamy flavour (low-creamy vs. high-creamy) on the self-selected consumption of a beverage, controlling for participant gender. Based on our previous finding that texture (effect size $r = 0.90$) and flavour (effect size $r = 0.74$) of a drink (repeated measures) influenced how filling it was expected to be (McCrickerd *et al.*, 2012) a sample size calculation was conducted, which indicated a minimum of eight participants would be needed to detect differences in expectations. However, it was assumed that the effect of these expectations on self-selected intake would be smaller, therefore based on a medium effect size ($r = 0.30$) a second calculation suggested a sample of 44 participants (22 males and females), which was taken to 48 so drink order could be counterbalanced across males and females.

4.3.3 Standard breakfast

On each test day all participants consumed a breakfast of cereal (“Crunchy Nut Cornflakes”, Kelloggs, UK: males 80g, females 60g), semi-skimmed milk (Sainsbury’s,

UK: males 200g, females 160g) and orange juice (Sainsbury's, UK: males 200g, females 200g). The breakfast provided the males with 540 kcal (2259 KJ) and the females with 440 kcal (1841 KJ), approximately 22% of an adult's daily average recommended energy intake.

4.3.4 Test drinks

The test drinks were based on the low-energy versions of a fruit beverage described in a previous study from our laboratory (McCrickerd *et al.*, 2012), formulated and prepared in the Ingestive Behaviour Unit at the University of Sussex. One hundred grams of the fruit drink base contained 23 kcal and consisted of 31g of fresh mango, peach and papaya fruit juice (Tropicana Products, Inc.), 17g 0.1% fat fromage frais (Sainsbury's UK), 41g of water and 11g of peach flavoured diluting drink (Robinsons from Britvic, UK). The drinks were prepared in four sensory contexts varying in thick texture and creamy flavours: thin/low-creamy; thin/high-creamy; thick/low-creamy; thick/high-creamy. Small quantities of tara gum (Kaly's Gastronomie, FR) were used to increase the viscosity of the drinks; the thin drinks contained 0.09g/100g of tara gum and the thick drinks 0.38g/100g. These amounts were based on our previous work which established that tara gum added in these quantities produced subtle but highly perceptible differences in the viscosity without effecting the taste and pleasantness of the drinks (McCrickerd *et al.*, 2012).

Creamy flavour was enhanced by the addition of vanilla extract (Nielsen-Massey, NL: 0.33g/100g) and milk-caramel favouring (Synrise, DE: 0.16g/100g) to the high-creamy but not to the low-creamy drinks. The two physical properties attributed to creaminess were measured for the four test drinks: viscosity, which relates to perceived thickness, and lubrication (smoothness). Viscosity measurements were conducted at 5°C on a Bohlin Rotational Rheometer (Malvern Instruments Ltd.) at shear rates 0.001-800 1/s using parallel-plate geometry (60 mm diameter) with a gap size of 1.0 mm. Lubrication properties were measured at room temperature (22 °C ± 1°C) on an MTM2 tribometer (PCS Ltd. London) using a stainless steel ball and elastomer disk (see: Mills, Norton, & Bakalis, 2013) at speeds between 1 and 1500mm/s. Figures 4.1 and 4.2 show the viscosity and lubrication profiles for all four test drinks and indicate that the thick drinks were more viscous and more lubricating (signified by a low traction coefficient) than the thin versions. Importantly, the creamy flavour additions did not influence the

physical texture of the drinks, therefore any differences in perceived creaminess and/or intake between the high- and low-creamy flavoured drink could be attributed to the additional flavour notes, rather than actual textural properties. None of the sensory manipulations added to the caloric value of the drinks.

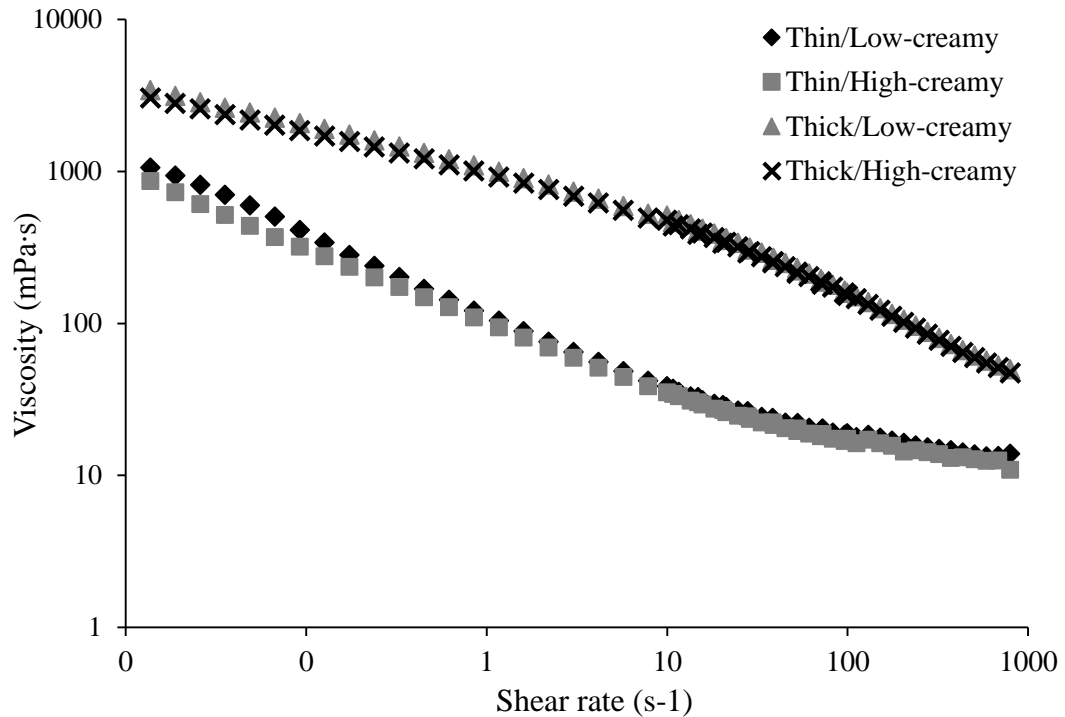


Figure 4.1 The viscosity of the four test drinks in millipascal-seconds (mPa·s) measured under shear, where a shear rate of between 10-100 s⁻¹ are thought to best represent in-mouth viscosity.

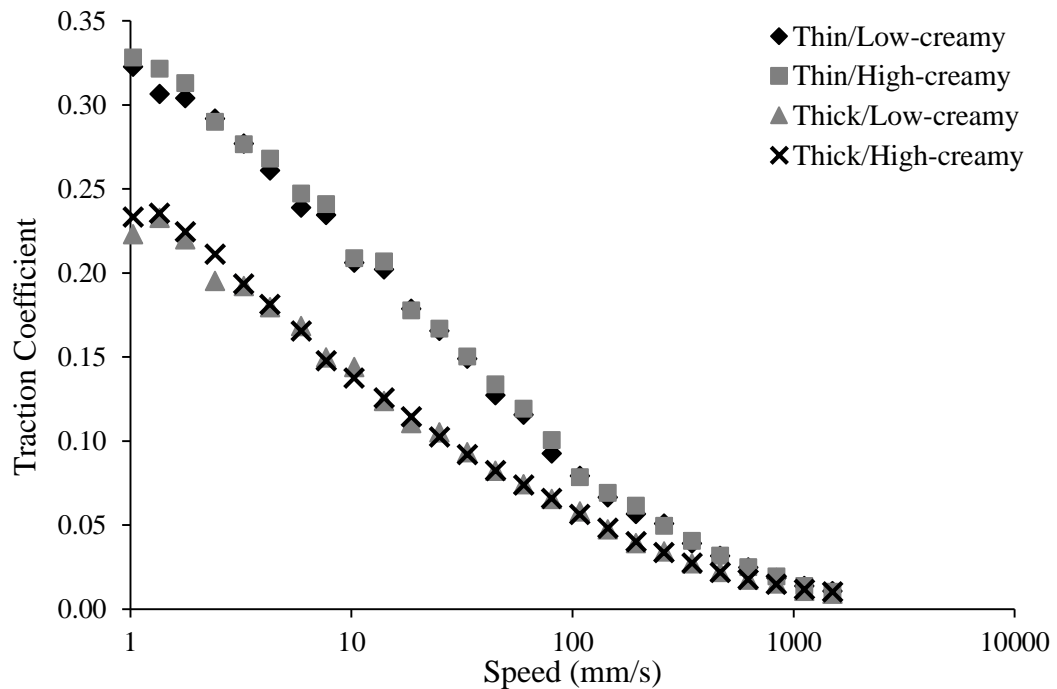


Figure 4.2 The lubricating properties of the four test drinks measured as a traction coefficient, where a lower traction coefficient represents a more lubricating sample.

4.3.5 Subjective appetite

Subjective measures of appetite were collected in the form of 100-point Visual Analogue Scale (VAS) ratings using the Sussex Ingestion Pattern Monitor (SIPM: Yeomans, 2000) running on a Dell PC using the windows XP professional operating system. Participants were asked “How <target> do you feel right now?” and instructed to indicate the extent to which they felt *hungry*, *full* and *thirsty* and their *desire to eat*, by dragging a marker along a 100mm scale. The scale response ranged from “Not at all <target>” (0) to “Extremely <target>” (100). These ratings were embedded amongst distracter “mood” ratings for how *calm*, *happy*, *clearheaded*, *anxious*, *tired*, *energetic*, *lively* and *alert* the participant felt. Each question was presented in a randomised order and only the appetite questions were analysed.

4.3.6 Sensory and hedonic evaluations of the drinks

Sensory evaluations of the drinks were also collected using the SIPM and had the same VAS format as the appetite ratings. Participants rated how *thick*, *creamy*, *familiar*, *fruity*, *pleasant* and *sweet* the drinks were, from “not at all” (0) to “extremely” (100). Like the appetite questions, each rating was presented in a randomised order.

4.3.7 Procedure

Participants completed four test sessions in the Ingestive Behaviour Unit (“food lab”) over four non-consecutive weekdays. To begin each session, the volunteers arrived at the laboratory for their standard breakfast at a pre-arranged time between 8.30-10.00am, and were required to have consumed only water since 11.00pm the previous evening. A measure of compliance to eating and drinking restrictions relied on participant self-report. On their first session all participants were reminded of the timings for the day’s session and of any eating and drinking restrictions. After breakfast, participants were instructed to leave the lab and return exactly two hours later having not consumed anything but water in that time or taken part in any strenuous activities.

On their return to the laboratory participants were shown to an air-conditioned testing cubicle with a PC computer where they completed the first set of appetite ratings. They were then presented with an opaque glass containing a 15g sample of a fruit drink alongside an opaque jug containing 900g of the same drink. The volunteers were instructed to taste the sample using a straw provided, hold it in their mouth while they

counted to three and then swallow, a method used to ensure sufficient oro-sensory exposure to the drinks (McCrickerd *et al.*, 2012). Participants then evaluated the sensory and hedonic properties of the drink and once this was complete they were informed that they could drink as much of the drink as they liked by pouring from the jug provided. They were informed that if they finished the jug they would always be provided with another one. Explicit expectations generated by the drinks sensory characteristics were not assessed again in this study to reduce the potential demand effects on intake after reporting beliefs about how filling the drink was expected to be. When participants had finished consuming the drink, the glass and jug were removed and they completed a final set of appetite ratings and then took a seat in the waiting room. This part of the study took approximately 10-20 minutes to complete. The total drink left in the glass and the total amount of drink consumed and left in the glass was calculated in grams immediately after the consumption phase. Future availability of food may influence intake in the laboratory if participants plan to eat once they have completed the test session. To control for this participants remained in the laboratory waiting area for 60 minutes after they had consumed the drink, where they were free to read/work but they were not able to consume anything but water. After this time, participants returned to the testing cubicle and completed a final set of appetite ratings and a simple reaction time test where participants responded to number strings. The reaction time test was used to corroborate the study's cover story, and like the mood ratings this was not analysed.

The order of presentation of the drinks across the four sessions was counterbalanced across participants. On the final test day participants completed a short set of questions where they were asked what they thought the purpose of the study was, what was the main reason they stopped drinking in the sessions (they could give more than one reason) and whether they thought that the food and drink they received was the same over the sessions. Once complete, participants had their height (cm) and weight (kg) measured and they were thanked, debriefed and paid £30 for taking part.

4.3.8 Data analysis

The main outcome measures were the total amount of fruit drink consumed, the total left in the glass, changes in rated appetite and sensory judgements. Intake data from one male participant was over 3 SD from the mean, causing significant skew in these data

on two out of four test days ($Z_{skew} > 0.21$, $p < 0.05$). After removal, these data were normally distributed. During the debrief, a second male participant reported to have over-consumed to the point of feeling sick in their first session, and consumed less in subsequent sessions because of this. Their data was also removed. Consequently, the data from 46 participants (22 males) were included in the analysis reported. A three-way mixed ANOVA contrasted the effect of drink thickness (thick vs. thin) and creamy flavour (low-creamy vs. high-creamy) on the total drink consumed (g) and the total drink that was left in the glass (g), with gender as the between-groups factor. Initially these analyses also included the order in which the drinks were consumed over the four sessions as a factor. However, order did not significantly affect overall intake and did not interact with the drinks sensory properties or participant gender to influence intake, therefore it was removed from the final analysis. Pearson's correlations were used to characterise the relationship between the total amount of drink consumed and participant BMI, restraint and disinhibition scores.

Initial analysis indicated that pre-test hunger, fullness, thirst and desire to eat ratings were similar at the start of all of the four test sessions and were not affected by participant gender. Thus, the main appetite analysis reported was conducted on change from baseline (pre-drink) data. A series of four-way mixed ANOVAs assessed the effect of time (post-drink vs. 60 minutes later), drink texture (thick vs. thin) and creamy flavor (low-creamy vs. high-creamy) across male and female participants on hunger, fullness, thirst and desire to eat ratings. One participant did not complete the final set of appetite ratings in one session and their data are missing from this analysis (represented in reduced *df*). Finally, three-way mixed ANOVAs assessed the effect of drink thickness (thick vs. thin) and the addition of creamy flavour (low-creamy vs. high-creamy) on the sensory and hedonic ratings of the test drinks, between male and female participants. The means and SEM are presented throughout the results section and Bonferroni adjusted comparisons were used to interpret any interaction effects. Pearson's coefficients (r) are reported for estimates of effects sizes for all main effects comparing two groups and for any planned comparisons (Rosnow, Rosenthal, & Rubin, 2000), where 0.50 represents a large effect, 0.30 a medium effect and 0.10 a small effect. As a measure of effect size Pearson's r represents the amount of variance in the outcome measure accounted for by the experimental manipulation.

4.4 Results

4.4.1 Total intake

Participants consumed less of the thick drinks compared to the thin drinks ($M_{thick} = 385 \pm 28\text{g}$, $M_{thin} = 418 \pm 32\text{g}$; $F(1,44) = 5.71$, $p = .021$, $r = 0.34$) and there was a trend for males participants to consume more than female participants overall ($M_{males} = 452 \pm 42$, $M_{females} = 352 \pm 40$; $F(1,44) = 3.00$, $p = .090$, $r = 0.25$). However, a significant thick * gender interaction indicated that only females consumed less of the thicker drinks ($F(1,44) = 4.08$, $p = .049$, see Figure 4.3). Separate one-way ANOVAs for male and female participants compared the total intake of the thick and thin drinks (using a Bonferroni adjusted significance level of $p < .025$). This indicated that the male participants consumed a similar amount of the thick and thin drinks ($M_{thick} = 449 \pm 42\text{g}$, $M_{thin} = 454 \pm 40\text{g}$; $F(1,21) = 0.09$, $p = .767$, $r = 0.07$), while the female participants tended to drink less of the thick drinks compared to the thin versions ($M_{thick} = 320 \pm 38\text{g}$, $M_{thin} = 383 \pm 44$; $F(1,23) = 8.14$, $p = .009$, $r = 0.51$); a reduction of 63g. There was no effect of creamy flavour on the total drink intake ($F(1,44) = 0.45$, $p = .508$, $r = 0.10$) and thick texture and creamy flavour did not interact to influence the amount of the drink consumed ($F(1,44) < 0.01$, $p = .984$) and this was true for both male and female participants ($F(1,44) = 0.17$, $p = .681$). There was no significant relationship between the amount of drink consumed in each session and participants' BMI, restraint (TFEQ-R) or disinhibition (TFEQ-D) scores (Table 4.1).

Table 4.1. Pearson's correlations (r) between total intake of each drink BMI, TFEQ Restraint (R) and TFEQ Disinhibition (D) scores, for male and female participants.

		Thin		Thick	
		Low-creamy	High-creamy	Low-creamy	High-creamy
BMI	Males	0.25 <i>ns</i>	0.34 <i>ns</i>	0.35 <i>ns</i>	0.14 <i>ns</i>
	Females	0.28 <i>ns</i>	0.17 <i>ns</i>	0.13 <i>ns</i>	0.10 <i>ns</i>
TFEQ-R	Males	-0.16 <i>ns</i>	-0.18 <i>ns</i>	-0.31 <i>ns</i>	< -0.01 <i>ns</i>
	Females	0.15 <i>ns</i>	-0.14 <i>ns</i>	0.14 <i>ns</i>	0.25 <i>ns</i>
TFEQ-D	Males	0.23 <i>ns</i>	0.13 <i>ns</i>	0.24 <i>ns</i>	0.08 <i>ns</i>
	Females	0.32 <i>ns</i>	0.26 <i>ns</i>	<0.01 <i>ns</i>	0.10 <i>ns</i>

ns: $p > .05$

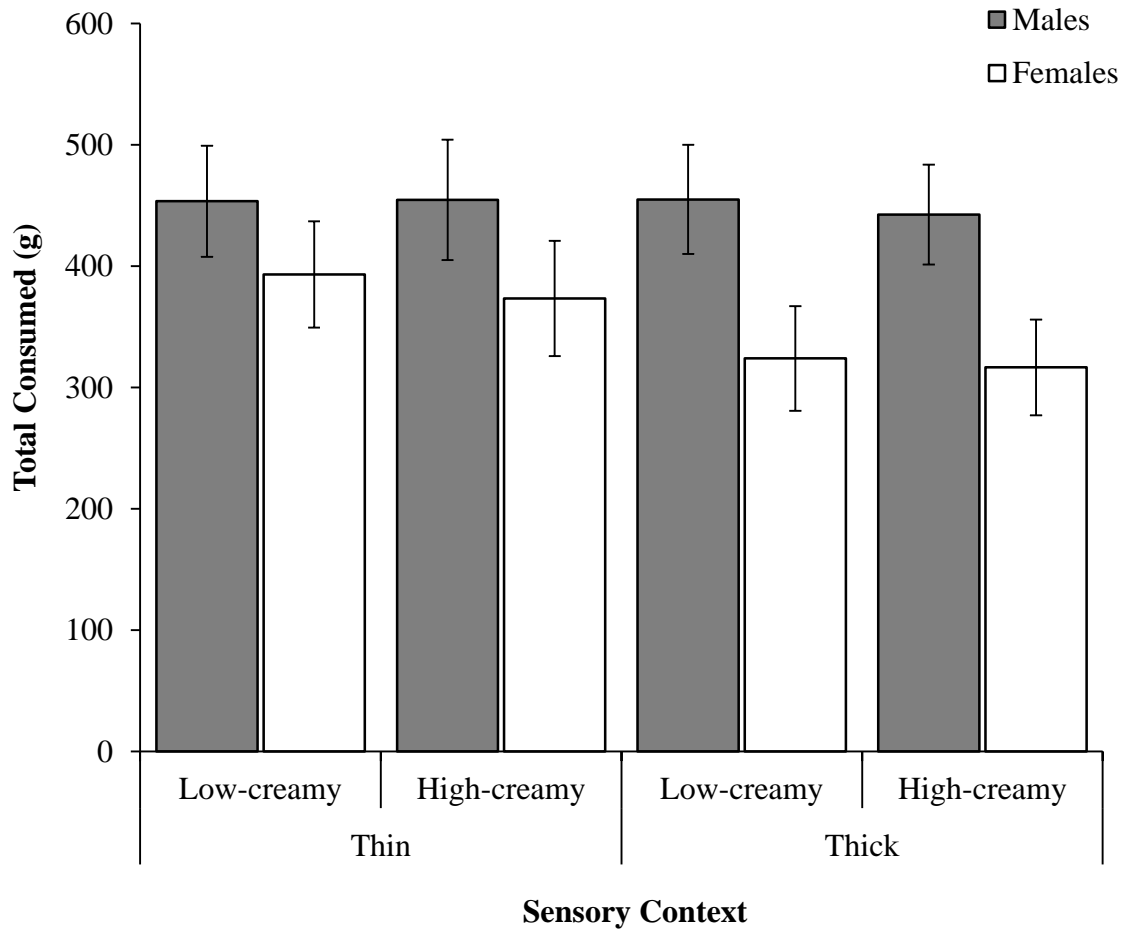


Figure 4.3 The total amount (g) of fruit drink consumed by male and female participants across the four sensory contexts. Error bars are based on SEM. Male participants consumed a similar amount of drink across the four sessions ($p = .767$), while female participants consumed less of the two thick drinks (high- and low-creamy) compared to the two thin versions (high- and low-creamy; $p = .009$).

4.4.2 Total left in the glass

At the end of the *ad libitum* consumption, participants appeared to leave slightly more of the thick drink in the glass compared to thin ones ($M_{thick} = 10 \pm 2g$, $M_{thin} = 4 \pm 1g$; $F(1,44) = 9.39$, $p = .004$, $r = 0.42$), probably because the increased viscosity caused a small amount of the thicker drinks to consistently remain on the sides of the glass.

There was no effect of creamy flavour ($F(1,44) = 0.00$, $p = .986$, $r < 0.01$) and no thick * creamy interaction ($F(1,44) = 1.46$, $p = .233$) on the amount of drink left in the glass after consumption and no effects of participant gender ($F(1,44) = 0.11$, $p = 0.742$, $r = 0.05$ and for all interactions with gender $p > .05$).

4.4.3 Changes in rated appetite

As expected there was a significant effect of time on all of the appetite ratings. Rated hunger ($F(1,43) = 69.24, p < .001, r = 0.79$), thirst ($F(1,43) = 28.32, p < .001, r = 0.63$) and desire to eat ($F(1,43) = 42.70, p < .001, r = 0.71$) decreased from pre- to immediately post-drink and then increased towards the pre-drink levels 60 minutes later, see Table 4.2. This pattern was mirrored in the fullness ratings which increased immediately after consumption of the drink and then decreased 60 minutes later towards the pre-drink levels ($F(1,43) = 77.88, p < .001, r = 0.80$).

Despite differences in total intake of the drinks between male and female participants, gender did not influence the changes in hunger, fullness, thirst and desire to eat (for each effect of gender $p > .05$ and $r < 0.21$; for all interactions with time $p > .05$). Furthermore, the drink's texture and creamy flavour did not affect the changes in hunger, fullness and desire to eat (for all main effects of thick and creamy flavour, $p > .05$ and $r < 0.15$; all thick * creamy interactions and all interactions with time, $p > .05$), see table 1. However, there was a significant thick * creamy interaction for the thirst ratings ($F(1,43) = 7.09, p = .007$) which indicated that overall the thin/high-creamy ($M = -31 \pm 4$) and thick/low-creamy ($M = -28 \pm 4$) drinks reduced thirst more than the thin/low-creamy drink ($M = -23 \pm 4$) and thick/high-creamy drink ($M = -20 \pm 4$), however, separate repeated measures *t*-tests (using a Bonferroni adjusted significance level of $p < .008$) revealed that none of the comparisons between the drinks reached significance ($p > .018, r > 0.23$). Changes in subjective thirst over time were not affected by the drink thickness or creamy flavour (for all interactions $p > .05$).

Table 4.2 Changes from baseline ratings of fullness, hunger, desire to eat and thirst for male and female participants across each of the drinks consumed, immediately after consumption (post-drink) and 60 minutes later. Numbers represent the mean (\pm SEM) VAS rating (where 0 = not at all, 100 = extremely).

		Thin				Thick			
		Low-Creamy		High-Creamy		Low-Creamy		High-Creamy	
		Post-drink	60 min	Post-drink	60 min	Post-drink	60 min	Post-drink	60 min
Fullness	Males	23 \pm 6	9 \pm 5	23 \pm 6	8 \pm 5	25 \pm 5	8 \pm 6	23 \pm 5	12 \pm 6
	Females	25 \pm 5	10 \pm 5	31 \pm 6	10 \pm 5	26 \pm 5	12 \pm 6	21 \pm 5	0 \pm 5
Hunger	Males	-13 \pm 5	-5 \pm 6	-16 \pm 5	-1 \pm 5	-20 \pm 6	-4 \pm 7	-17 \pm 5	-10 \pm 7
	Females	-21 \pm 5	-9 \pm 5	-25 \pm 5	-4 \pm 5	-20 \pm 6	-5 \pm 7	-23 \pm 5	-1 \pm 7
Desire	Males	-13 \pm 6	-4 \pm 6	-12 \pm 5	-2 \pm 5	-20 \pm 5	-3 \pm 7	-17 \pm 6	-10 \pm 8
	Females	-19 \pm 6	-3 \pm 5	-23 \pm 5	-1 \pm 5	-18 \pm 5	-1 \pm 7	-18 \pm 6	-5 \pm 7
Thirst	Males	-27 \pm 6	-18 \pm 6	-25 \pm 6	-20 \pm 6	-30 \pm 6	-17 \pm 6	-21 \pm 6	-14 \pm 5
	Females	-30 \pm 6	-16 \pm 5	-43 \pm 6	-34 \pm 6	-37 \pm 6	-27 \pm 5	-27 \pm 6	-17 \pm 5

4.4.4 Sensory and hedonic ratings of the drinks

The mean sensory and hedonic ratings for each of the drinks are reported in table 3. There was no effect of the thick and creamy sensory manipulations on the perceived fruitiness, sweetness, pleasantness and familiarity of the drinks (for all main effects of thick texture and creamy flavour $p > .05$ and $r < 0.15$, and for all thick * creamy interactions $p > .05$). Perceived thickness and creaminess was affected by the sensory manipulations. The thick drinks were rated as thicker than the thin drinks ($F(1,44) = 42.34$, $p < .001$, $r = 0.70$) and there was a trend for the high-creamy drinks to be perceived as slightly thicker than the low-creamy versions ($F(1,44) = 0.34$, $p = .072$, $r = 0.27$). The low-creamy drinks were perceived to be equally creamy as the high-creamy flavoured drinks ($F(1,44) = 1.98$, $p = .166$, $r = 0.21$) but the thick drinks were rated as creamier than the thin drinks ($F(1,44) = 10.13$, $p = .003$, $r = 0.43$). Thick texture and creamy flavour did not interact to influence thick and creamy ratings ($p > .05$). Finally, there was no effect of gender on any of the sensory and hedonic ratings ($p > .05$ and $r < 0.19$ for all main effects) and no interactions ($p > .05$).

Table 3. Sensory and hedonic evaluations of the test drinks. Numbers represent the mean (\pm SEM) VAS rating (where 0 = not at all, 100 = extremely).

	Thin		Thick		<i>p</i> -value
	Low-creamy	High-	Low-creamy	High-	
Thick	44 \pm 3 ^a	48 \pm 3 ^a	61 \pm 3 ^b	64 \pm 3 ^b	< 0.001
Creamy	54 \pm 3 ^a	56 \pm 3 ^a	61 \pm 3 ^b	64 \pm 3 ^b	0.003
Fruity	66 \pm 2	64 \pm 3	64 \pm 2	65 \pm 2	<i>ns</i>
Sweet	65 \pm 3	65 \pm 3	64 \pm 3	64 \pm 3	<i>ns</i>
Pleasant	69 \pm 3	71 \pm 2	70 \pm 3	71 \pm 3	<i>ns</i>
Familiar	61 \pm 4	64 \pm 4	68 \pm 3	63 \pm 4	<i>ns</i>

For each set of ratings *ns* represents non-significant at $p > .05$. Within the same rating, values marked with different letters were statistically different ($p < .05$) whereas those with the same letters were statistically similar ($p > .05$), determined using Bonferroni corrected comparisons.

4.4.5 Participant feedback

Most of the participants (85%) reported that they thought the study was assessing the effects of the foods they were consuming on ‘mood’ and feelings of ‘alertness’ and

‘energy’, in line with the cover story. One participant said they had no idea what the purpose of the study was and the remaining 13% of the participants made other suggestions, such as market research for the drinks and testing the drink as an alternative to breakfast and lunch. Forty three percent of the participants reported that the most important reason they stopped drinking was because they felt full and 18 % reported that it was because they no longer felt thirsty. Only one person reported that the main reason for stopping drinking was that they had reached the bottom of the glass, and one that they had finished the bottom of the jug. Regarding the sensory differences, 54% of participants reported that the drinks were different, mostly commenting on textural differences, and 12% reported that they were different but unsure how, but 34% of the participants believed that the four drinks were the same. Interestingly, the mean intake values for those who reported that the drinks were the same across the four sessions revealed a similar pattern to the one reported in the main analysis, with female participants tending to reduce intake in response to the thick drinks ($M_{thin} = 326 \pm 52g$, $M_{thick} = 268 \pm 42g$), with little evidence of this in the males ($M_{thin} = 577 \pm 67g$, $M_{thick} = 576 \pm 54g$).

4.5 Discussion

The key finding from this study was that increasing the *perceived* thickness and creaminess of a drink reduced intake in female participants. This builds on previous work suggesting that increasing the viscosity of a drink increases the extent to which it is expected to be satiating and suggests that such expectations can influence actual eating behaviour. The majority of participants consumed all of the drink that they served themselves, indicating that the reduced intake of thicker drinks was because female participants poured out less of these versions, which is in line with research suggesting that pre-meal expectations of satiation and satiety are important determinants of meal size (Fay *et al.*, 2011a; Wilkinson *et al.*, 2012). The most common reason participants reported for stopping drinking over the four sessions was feeling full and appetite ratings suggested that the participants did feel equally full after each version of the drink, despite consuming different amounts. Thus the drinks with satiety-relevant characteristics lead to a reduction in intake in female participants without affecting subjective fullness. A key question for future research would be whether sensory-related reductions in intake are compensated for in later meals.

In this study only the textural manipulation elicited a significant decrease in consumption. This builds on our previous work indicating that a subtly thicker drink was expected to be more satiating than a thinner version, with the addition of creamy flavour cues having less of an effect on these expectations (McCrickerd *et al.*, 2012), but contrary to our prediction the addition of creamy flavours had no impact on intake. However, *perceived* creaminess was associated with a decrease in consumption. In this study, as well as in our last, the thicker drinks were consistently rated as thicker and creamier than the thin versions. This is because perceived ‘creaminess’ is a complex sensory attribute, and characterised by both flavour and texture cues (De Wijk *et al.*, 2006; Kirkmeyer & Tepper, 2005). Human adults have consumed a range of foods and drinks in their lifetime, and with this experience, come to learn about their satiating consequences. These learned associations between a food's sensory properties and post-ingestive consequences are likely to form the basis of expectations about the how filling a food will be (Brunstrom, 2007). One possibility is that over a lifetime increased viscosity is simply a more salient predictor of nutrients in food and drinks, compared to creamy flavours alone which naturally occur in combination with changes in viscosity

and lubrication. Interestingly, one third of the participants reported that they perceived no differences in the four drinks, highlighting that even though the sensory manipulations changed behaviour they were subtle enough to not always be remembered. Indeed, in the current study the four drinks were consumed across four non-consecutive days. This limits the extent to which the participants could ‘compare’ the drinks and highlights just how subtle the sensory manipulations were, with the creamy flavour additions being less noticeable than the difference in viscosity.

Why then should only the female participants alter their intake of a drink in response to its texture? Male and female participants were matched on characteristics previously thought to influence *ad libitum* intake, namely BMI, dietary restraint and disinhibition, as well as reporting similar appetite sensations prior to consuming the drink (Blundell *et al.*, 2010; Herman & Polivy, 2008). The drinks were all equally energy-dense and the order with which males and females consumed the different drinks over the sessions did not affect intake behaviour, suggesting that differences in intake cannot be explained by nutrient learning effects. Moreover, all participants rated the drinks as similarly pleasant, sweet and familiar and both male and female participants perceived the thick drinks to be thicker and creamier than the thin versions, so it is unlikely that perceived differences in these characteristics influenced intake differentially in these groups. The decision not to re-test satiety expectations in this study was taken to reduce the potential for response bias on intake, but this means that we can only assume males and females held similar expectations that the thicker and creamier drinks would be more satiating. However, gender differences in satiety expectations based on the sensory characteristics of foods and drinks have not been previously reported (Hogenkamp *et al.*, 2011; McCrickerd *et al.*, 2012).

An alternative explanation for the males in this study not adjusting their intake in response to the sensory manipulations is that there was another more salient influence on meal size in this group. Research investigating *ad libitum* consumption of drinks differing in viscosity reported that participants consumed less of a thicker semi-solid drink compared to a less viscous liquid version, and there was no evidence that this effect depended on the participant’s gender (Zijlstra *et al.*, 2008). But a key difference between that and the current research is that Zijlstra and colleagues removed an important environmental cue for meal termination from their study: finishing the

serving (Fay *et al.*, 2011a). In the present study males consumed on average 451g of the drinks, which was 100g more than female participants and almost exactly the same amount as the capacity of the glass (450-470g depending on whether it was filled completely to the brim or just below). This suggests that for many of the male participants, their desired portion size was probably greater than the maximum amount of drink that could be held in the glass, and in order to consume this amount they had to pour a second helping of the drink. Perhaps this portion size cue limited the influence of satiety expectations on self-selection in the male participants more than the female participants, whose average serving size was much less than the capacity of the glass. To increase the sensitivity of the study design, we would need to provide participants with a big enough glass to reduce this bias. However, decanting a portion of a drink from a larger container is arguably more applicable to real consumer behaviour and perhaps what the current study actually demonstrates is the subtlety with which satiety expectations are likely to influence real life portion size decisions in the face of other salient serving size cues and portion norms.

4.5.1 Conclusion

This study indicates that increasing the perceived thickness and creaminess of a drink, by subtly increasing its viscosity, led female participants to consume less of the drink but feel no less satisfied, lending support to the idea that a food's sensory characteristics generate expectations of satiation and satiety that can guide eating behaviours. An unexpected outcome was that the sensory characteristics of the drink did not influence intake in the male participants, despite previous research suggesting that both males and females expected a thicker drink to be more satiating. This highlights that multiple external factors are likely to influence meal size selection and consumption not just in solid foods, but drinks too

4.5.2 Abbreviations

mPa·s: millipascal-second; s⁻¹: reciprocal seconds; mm·s⁻¹: millimetres per second; MTM2: Mini-Traction-Machine tribometer; SEM: standard error of the mean.

4.5.3 Author contributions

This research was funded by the BBSRC and DRINC initiative and conducted as part of a PhD studentship. KMc, MRY and LC designed the study. KMc prepared the study materials, collected and analysed the data, including the viscometry, and drafted the manuscript with commentary from LC and MRY. All authors read and approved the final manuscript. The authors declare that they have no competing interests. The authors would like to thank Jennifer Norton and Tom Mills at the University of Birmingham Department of Chemical Engineering for access to the rheometer used to conduct the viscosity measurements, and extra thanks to Tom Mills for collecting the tribology measurements.

5. Paper four

Can satiety-relevant labelling improve the anticipated and actual satiating effect of beverages with enhanced sensory characteristics?

Keri McCrickerd^{1*}, Lucy Chambers¹ and Martin R. Yeomans¹

¹ *School of Psychology, University of Sussex, Brighton, UK*

5.1 Abstract

Product labelling is one practical way to generate beliefs about the potential satiating effect of a food that may play an important role in energy intake regulation. The present study investigated the possibility that a caloric beverage presented with satiety-relevant cues, generated by labelling and sensory characteristics, would be expected to be more satiating and have a greater impact on the subsequent experience of satiety than the same beverage without these added cues. Forty-eight female participants attended two test days where they consumed a *lower-energy* (LE, 78 kcal) and *higher-energy* (HE, 279 kcal) version of a beverage (covertly manipulated within-groups). The beverage was presented in one of two sensory contexts (*thin/low-creamy* vs. *thick/high-creamy*, measured between-groups) and one of three labelling groups (*no label* vs. *congruent label* vs. *incongruent label*, measured between-groups). In the congruent label condition the HE beverage was consumed with a high-satiety label (“*Stay-full: feel fuller throughout the day*”) and the LE beverage with a low-satiety label (“*Lighten: drink between meals without filling you up*”), and this was reversed in the incongruent label condition. Food diaries were used to record all food and drinks consumed on each test day. Satiety was indexed by rated appetite, the time and size of the first eating episode after consuming the beverage, and the total energy intake over the course of the test day. Results suggest that both labelled satiety messages and thick and creamy sensory characteristics enhanced the expectation that the beverage would be filling, but no significant differences were found in actual satiating power post-consumption, although there was tentative evidence that participants adjusted later energy intake in response to consuming the higher-energy beverage with the high-satiety label and sensory cues. These data provide preliminary evidence for the ways in which the cognitive, sensory and nutrient characteristics of a caloric beverage might be combined to optimise their anticipated and actual satiating power.

5.2 Introduction

The experience of satiety (the suppression of hunger and subsequent eating in the time after a meal or eating occasion) is more than just the physiological effect of ingested nutrients; thoughts, beliefs and expectations about the foods and beverages we consume play an important role in energy intake regulation (Blundell *et al.*, 2010; Blundell *et al.*, 1987), and our perception of the foods we consume is a potentially important determinant of its actual satiating effect. This is particularly relevant to the regular consumption of caloric beverages, which may not be considered to be satiating (Mattes, 2005), and are thought to contribute to weight gain by having a weak impact on appetite regulation compared to the same energy consumed in other food forms (Cassady *et al.*, 2012; Flood-Obbagy & Rolls, 2009; Mattes, 2005; Mattes & Campbell, 2009; Mourao *et al.*, 2007). The current study investigated the possibility that enhancing the perceived satiating effect of caloric beverages can influence their satiating power.

Product labels such as “high fat” or “low salt” are an effective way to influence the perception of a food or beverage, generating beliefs and expectations (not necessarily good ones) that can affect perceived taste properties and pleasantness (Liem, Aydin, & Zandstra, 2012a; Liem, Miremadi, Zandstra, & Keast, 2012b; Wansink & Park, 2002; Wansink, van Ittersum, & Painter, 2005b; Wardle & Solomons, 1994) and even the experience of satiety post-consumption (Caputo & Mattes, 1993; Shide & Rolls, 1995), although not always (Yeomans *et al.*, 2001). Labels influencing the expected consequence of consuming a product may impact its actual satiating power. Foods labelled as “high calorie” vs. “low calorie” were experienced as more satiating (Hogenkamp *et al.*, 2013; Wooley, 1972), and Crum *et al.* (2011) demonstrated that a milkshake labelled “high-calorie” and “indulgent” elicited a smaller decline in the orexigenic (appetite stimulating) hormone ghrelin, compared to the same milkshake labelled as “low calorie” and “Sensi-shake”. However, satiety-relevant labelling, including those used by Crum *et al.*, do not always elicit changes in appetite and future intake (Chambers *et al.*, 2013; Crum *et al.*, 2011). It is possible that satiety-relevant labels and slogans have less impact on the experience of satiety when they are inconsistent with, or overshadowed by, expectations generated by a product’s sensory characteristics and the energy delivered post-ingestion.

Sensory cues, such as thick texture (Hogenkamp *et al.*, 2012b; Hogenkamp *et al.*, 2011) and chewiness (Forde *et al.*, 2013) are associated with expectations of ‘fullness’. In beverages, which have a characteristically weak oro-sensory impact, McCrickerd *et al.* (2012) demonstrated that subtle increases in thick and creamy sensory cues increased the expectation that a beverage would be filling and suppress hunger. But, rather than having a general effect on satiety, expectations generated by these sensory cues *interact* with a beverage’s actual energy content to influence satiety in the period after consumption: Yeomans and Chambers (2011) showed that participants consuming sensorially-matched higher- and lower-energy versions of a fruit-beverage found them equally satiating when they were presented in a thin and low-creamy sensory context, despite consuming 200 kcal extra in the higher-energy version. However, when consumed in a subtly thicker and creamier sensory context (the context that was expected to be more satiating) participants felt less hungry and ate significantly less at lunchtime after the higher-energy beverage, but not the lower-energy version. This suggests that a higher-energy beverage will be most satiating when it’s sensory cues are predictive of nutrients, and has been replicated in several recent studies (Bertenshaw *et al.*, 2013; Chambers *et al.*, 2013; McCrickerd, Chambers, & Yeomans, 2014b; Yeomans *et al.*, 2014).

The current study investigated the possibility that expectations generated by satiety-relevant labelling could also improve the satiating power of a caloric beverage, specifically when they are congruent to the beverage’s sensory and nutrient characteristics. Female participants consumed a higher-energy (279 kcal) and lower-energy (78 kcal) beverage in one of two sensory contexts (thin/low-creamy or thick/high-creamy), with or without satiety-relevant labels and slogans: “*Stay-full: feel fuller throughout the day*” and “*Lighten: drink between meals without filling you up*”. The beverage labels were presented either congruent or incongruent to the beverage’s actual energy content, across both sensory contexts. It was predicted that the beverage combining the high-satiety label and enhanced sensory characteristics would be *expected* to be most satiating pre-consumption, and would have the largest actual satiating power post-consumption when combined with the higher-energy content. All previous studies investigating the effect of cognitive or sensory enhancement of satiety have measured intake in a laboratory setting, which is arguably not representative of real-world eating situations (Blundell *et al.*, 2010; Meiselman, 1992). Thus, satiety was

determined by measuring subsequent free-living energy intake using 24-hour food diaries, with the aim to test the translation of these effects to less controlled, more real-world eating behaviour. Of particular interest was the time and size of the next spontaneous eating episode after consuming the beverages, and the extent to which participants compensated for the additional energy consumed in the higher-energy version over the course of the day.

5.3 Method

5.3.1 Participants

Fifty female participants were recruited from a volunteer database at the University of Sussex. All gave informed consent to take part in a study “Investigating the interaction between real eating behaviours and mood”. Participants were non-smokers, were not currently dieting, had normal or corrected to normal vision and were regular breakfast consumers (≥ 5 times a week). Other exclusion criteria included currently taking prescription medication, athletes in training and anyone with allergies or aversions to any of the test materials. Participant age ranged from 18-28 ($M = 21$, $SD \pm 3$) with a BMI within the normal range (range = 18-27 kgm^{-2} , $M = 23 \text{ kgm}^{-2}$, $SD \pm 2$, where $<18 \text{ kgm}^{-2}$ is classed as underweight, 18-25 kgm^{-2} healthy, 25-30 kgm^{-2} overweight and 30+ kgm^{-2} obese), and participants were selected to score low on a measure of restrained eating (< 7 on the Three Factor Eating Questionnaire restraint sub-scale: Stunkard & Messick, 1985).

5.3.2 Design

A three-factor 2 x 2 x 3 mixed design was run single blind, with the beverage *energy content* (lower-energy (LE) vs. higher-energy (HE)) as a within-group factor, and beverage *sensory context* (thin and low-creamy vs. thick and high-creamy) and *satiety-relevant labelling* (no label vs. congruent label vs. incongruent label) two between-subject factors. An outline of this design is presented in Table 5.1. A power calculation was conducted based on a previous finding that the energy content of these beverages interacted with their sensory context to influence subsequent meal size (effects size $f = 0.4$, power $> 0.95\%$: Yeomans & Chambers, 2011). Using a smaller estimated effect size (size $f = 0.025$, power $> 0.90\%$) this indicated a sample size of 72 participants ($n = 12$ in each group). Fifty participants were recruited within the initial time frame of the study and unfortunately one of the beverage’s key base ingredients was then discontinued, ceasing the opportunity for further data collection. The University of Sussex Ethics Committee approved the study. All participants gave written consent and received £30 for taking part.

Table 5. 1 Details of the six experimental groups (identified by different colour-blocks). The effect of the beverage's energy content was measured within-participant whereas the labelling and sensory contexts were measured between groups.

	Thin		Thick	
	Low-creamy		High-creamy	
	LE	HE	LE	HE
No label	LS LE no label <i>n</i> = 9	LS HE no label	HS LE no label <i>n</i> = 8	HS HE no label
Congruent	LS LE low satiety label <i>n</i> = 8	LS HE high satiety label	HS LE low satiety label <i>n</i> = 8	HS HE high satiety label
Incongruent	LS LE high satiety label <i>n</i> = 8	LS HE low satiety label	HS LE high satiety label <i>n</i> = 9	HS HE low satiety label

5.3.3 Test drinks

There were four drink preloads varying in energy content (higher-energy, HE: 279 kcal; lower-energy, LE: 78 kcal) and sensory context (thin/low-creamy or thick/high-creamy). The ingredients, macronutrient and energy composition of the four drink preloads are presented in Table 5.2. All the drinks were prepared in the Ingestive Behaviour Unit at the University of Sussex and were based on the drinks used in previous research (Chambers *et al.*, 2013; Yeomans & Chambers, 2011). The thick/high-creamy versions contained small quantities of tara gum to increase viscosity, and milk caramel flavour and vanilla extract to increase the creamy taste. Maltodextrin and whey protein were added to the HE versions. The drinks were matched for colour and flavour and small quantities of aspartame and tara gum were added to the LE versions to account for the extra sweetness and thickness caused by the maltodextrin and protein in the HE versions. Pilot-testing, described in Yeomans and Chambers (2011), indicated that the thick/high-creamy versions were perceived to be thicker and creamier than the thin/low-creamy versions, whilst the drinks were matched for perceived thickness, creaminess and sweetness across the HE and LE versions. The

drinks were described to the participants as a “tropical fruit lassi” and were presented in a transparent plastic bottle with or without a label attached.

Table 5.2 Ingredient and nutrient details of the four test beverages

Per 300g serving		Thin		Thick	
		Low-creamy LE	HE	High-creamy LE	HE
Base^a	Pomegranate juice ^b (g)	220	180	220	180
	Orange and mango squash ^c (g)	30	30	30	30
	Fromage frais ^b (g)	50	25	50	25
Energy manipulation	Maltodextrin ^d (g)	0	35	0	35
	Whey protein isolate ^e (g)	0	25	0	25
Sensory manipulation	Tara gum ^f (g)	0.3	0	0.9	1.5
	Milk caramel ^g (g)	0	0	0.3	0.3
	Vanilla extract ^h (g)	0	0	1	1
	Aspartame ⁱ (g)	0.03	0	0.03	0
Total nutrients	Total fat (g)	0	0.3	0	0.3
	Total carbohydrate (g)	13	43	13	43
	Total protein (g)	4.1	24.4	4.1	24
	Total energy (kcal)	78	279	78	279

a Small quantities of rhubarb and yogurt flavouring were also added equally to all of the drink bases, and colour was matched across the drinks with small additions of red and yellow food colouring (Silverspoon).

b Sainsbury's UK

c Britvic UK

d Cargill UK

e Myprotein Inc. UK

f Kaly's Gastronomie, FR

g Synrise

h Nielsen-Massey, NL

i Ajinomoto Europe.

5.3.4 Labels

The test labels were designed to provide information about the potential satiating effects of the drinks and are presented in Figure 5.1. There were two labelled messages, one

with a high-satiety label and strapline (“*Stayfull: feel fuller throughout the day*”) and a low-satiety version (“*Lighten: drink between meals without filling you up*”), which were presented in one of two colours (yellow or pink, counterbalanced across participants). In the congruent label condition the messages on the labels were in-line with the nutrient content of the drink they received, such that the LE drink was labelled “*Lighten*” whereas the HE version had the “*Stay full*” label. The opposite was true for those participants in the incongruent condition, who consumed the HE drink labelled “*Lighten*” and the LE version labelled “*Stay full*”. Two pilot studies, reported in detail by Chambers, Ells and Yeomans (2013), were conducted to select and pair-up the high- and low-satiety brand names and straplines. Initially, participants in the first pilot ($n=24$) assessed a selection of 12 potential brand names and 12 straplines for how pleasant and satiating they would expect a drink with the brand name/strapline to be, and those that elicited the strongest and weakest expectations of satiety were selected. Another set of participants ($n=24$) then evaluated the possible combinations of brand names with the straplines, and the brand name/strapline combinations that were expected to deliver the most and least satiating product were used in the present study.



Figure 5.1 The four high- and low-satiety labels. Participants received either a yellow or a pink version, completely counterbalanced across participants and conditions.

5.3.5 Food diary and recording pack

Each participant received a food record pack containing an A5 paper food diary, a pen, a digital camera and a set of measuring cups to record all food and drink items (excluding water) consumed over the 24 hours of each test day.

The food diary was set out for participants to give a detailed record of the type and quantity of food and drink consumed (and any leftovers), the time of consumption, method of cooking, brand names (where necessary), and a check box to tick off when a photo had been taken. Each diary contained written instructions and example pages (covering examples of a variety of foods, beverages, quantities, cooking styles and leftovers) for participants to refer back to during their use. The main record pages were split over two days and the beginning of each day started with a prompt for participants to write down what they had for breakfast prior to the test session. See Appendix 5.1 for a full example of the food diary.

Each participant was required to take an overhead picture of all the food items they consumed and all leftovers in the 24 hours using a Kodak EasyShare M530 12 megapixel camera (supplied fully charged with a 4GB Sandisk memory card). In order to reduce the participants' workload, pictures of beverages were not required. The picture method was used to improve compliance and accuracy of the record and limit underreporting (de Castro, 2010), and participants were asked to always clearly place the edge of their food diary next to the food in each photo (see Figure 5.2 for an example); a border consisting of a 1 cm pattern was added to the diary to provide a covert point of measurement for the experimenter, although participants were told this was to identify each picture with the correct participant number.

The recording pack also contained three plastic measuring cups (1 cup, $\frac{1}{2}$ cup and $\frac{1}{4}$ cup) to further aid the measurement of the food and drink items consumed. Participants were instructed to use these to record any quantities that were deemed ambiguous (such as a handful) and it was anticipated that the cup measurements would be less familiar than grams and kilograms, millilitres and litres, so less likely to prompt/bias the quantities consumed. A pilot study of the use of the diary ($n = 5$) confirmed that there was enough space to record the food items over the test days and that all instructions and examples were clear.

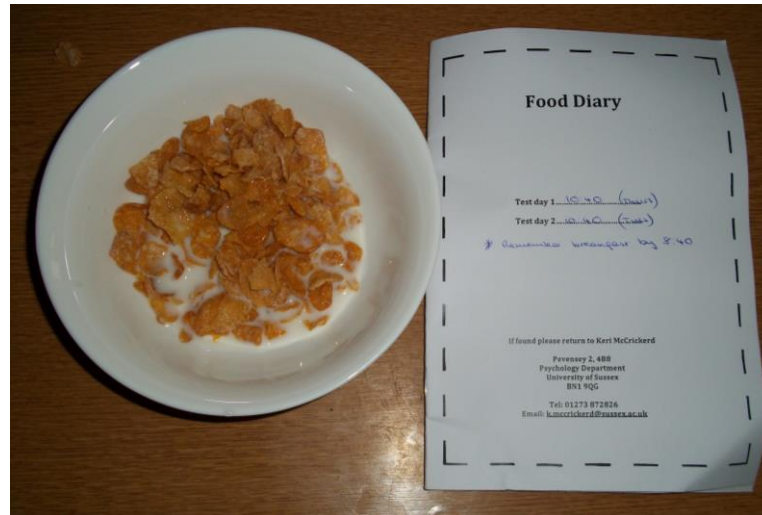


Figure 5.2 Example photograph. Participants were asked to clearly place the edge of the food diary in each photograph.

5.3.6 Diary coding

Food diaries were analysed using Dietplan6 (Forestfield Software Ltd, UK) containing food tables from the McCance & Widdowson Composition of Food Series, based on the Food Standards Agency's UK Nutrient Databank, and other imported relevant databases available from food manufacturers. Each food diary and corresponding photographs were assigned a code so the experimenter recording the nutritional information was blind to each participant's experimental condition. The following data needed to be extracted from the food diary for each test day:

- Time until first eating episode after the drink
- Size of the first eating episode
- Total daily energy intake

In order to calculate the size and time of a first eating episode, an eating episode was defined as > 50 kcal consumed at least 20 minutes apart from further intake, which was selected based on criteria for defining eating episodes set out by (de Castro, 1994). During analysis of the food diary the written records consistently checked against the relevant photograph to make sure all items were correctly recorded

5.3.7 Procedure

Participants were required to attend the laboratory on four occasions during a single week: a training session (Monday), then two non-consecutive test-days (Tuesday and Thursday) and a debrief session (Friday). The training session was used to issue participants with a recording pack and to familiarise them with the recording tools. All participants were issued with the same instructions for completing the diary, taking photos (using examples of correct and incorrect picture taking) and using the measuring cups. During this time there was the opportunity to practice using the camera and ask any questions about completing the diary records. The training session emphasised the need for participants to be honest about their diary records to help the study in its aim to investigate “real eating behaviours and mood”, and motivated participants to complete the records fully.

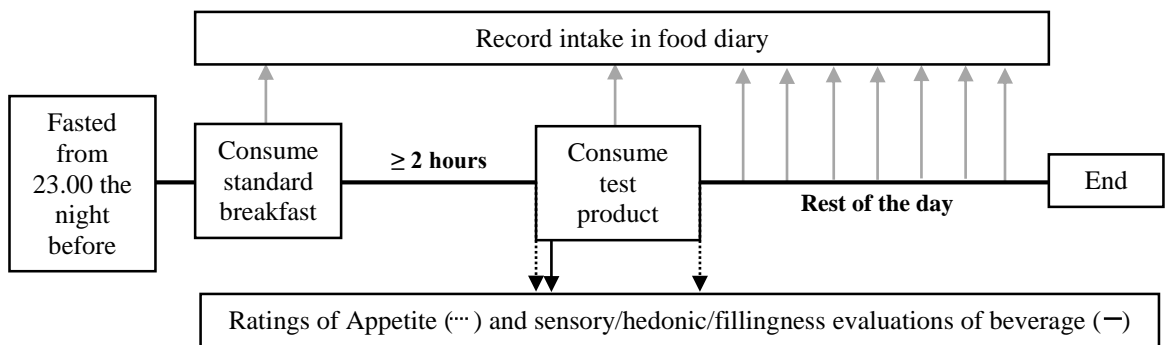


Figure 5.3 Schematic summary of the test day procedure.

After the training day participants completed the two test days (procedure illustrated in Figure 5.3), fasting from 11 pm the night before and recording their intake from the moment they awoke each day until they went to bed in the evening. Participants were required to consume their regular breakfast (and record this in their diary) at least two hours before attending the laboratory to consume their beverage at a prearranged time between 10-11 am. A measure of compliance to eating and drinking restrictions relied on participant self-report and diary entry. When they arrived at the lab an experimenter checked the breakfast record and showed the participants to a testing cubicle with a Dell PC computer running the Sussex Ingestion Pattern Monitor (SIPM: University of Sussex; Yeomans, 2000) software. Participants began by completing a set of computerised appetite ratings disguised amongst a series of “Mood questions”, indicating the extent to which they felt *hungry*, *full* and *thirsty* by placing a marker

along a 100mm Visual Analogue Scale (VAS) in response to the question “How <target> do you feel right now?”. The VAS anchors ranged from “Not at all <target>” (0) to “Extremely <target>” (100) and the target appetite ratings were embedded amongst the distracter “mood” ratings for how *calm*, *happy*, *nauseous*, *clearheaded*, *anxious*, *tired*, *energetic*, *lively* and *alert* they felt. All of these questions were presented in a randomised order. Once complete participants received their beverage and those who received a label were asked to read the label and identify its colour; this was to ensure participants read the labelling. All participants then tasted the beverage with a straw and made more 100-point VAS ratings in response to the question “How <target> is the drink?”, evaluating how *thick*, *creamy*, *pleasant*, *sweet* and *familiar* the drinks tasted, and how *filling* they expected it to be (note that the filling expectation was measured when participants had experienced both the label and the sensory cues). These ratings were also completed in a randomised order and once complete participants were prompted to consume the rest of their beverage. The session ended with a final set of “mood” questions and then participants were free to leave the laboratory with their recording pack. Participants recorded all of the food and drink they consumed (excluding water) in their food diary for the rest of the day.

After the first test-day, participants had a rest day before completing the second test day following the same procedure. Sensory and label characteristics depended on test condition (detailed previously in Table 5.1) but all participants consumed the HE version on one day the LE version on the other; the order of which was counterbalanced across experimental groups. Once both test days were complete, participants attended the laboratory for a final debrief session. Here participants returned their recording packs to the experimenter and were asked to identify any problems they may have had with their food records. They then completed a short debrief questionnaire where they were asked to identify what they thought was the purpose of the study and whether they felt the food diary affected how/what they ate (and if so, how). Height and weight measurements were recorded and participants then received £30, were debriefed and thanked for taking part.

5.3.8 Data Analysis

The study aimed to test the expected and actual satiating effects of a beverage depending on its labelled, sensory and nutrient characteristics. A series of mixed-

ANOVAs were used to test the effect of the beverage's *energy content* (within-groups: LE vs. HE), *sensory context* (between-groups: thin/low-creamy vs. thick/high-creamy), and *labelling* (between-groups: no label vs. congruent label vs. incongruent label) on the key outcome measures of expected fillingness, time until the first eating occasion (minutes), the size of the first eating occasion (kcal), total daily energy intake (kcal), compensation in response to the beverage's energy difference (percent compensation), and the sensory and hedonic ratings of the beverages. The same ANOVA was used to analyse changes in rated appetite but with *rating time* (within-groups: *pre-beverage* vs. *post-beverage*) as an additional factor in these analyses. Percent compensation values were calculated to describe the degree to which participants adjusted their overall daily energy intake in response to the additional energy (201 kcal) consumed in the HE beverage compared to the LE version ($[(\text{total daily energy intake}_{LE\ day} - \text{total daily energy intake}_{HE\ day})/201] * 100$). A value of 100% represents compensation for all of the 201 extra calories in the HE beverage, by eating 201 kcal less on that day compared to the day they consumed the LE version.

Data from three participants were not included in the analysis: the intake data from two participants were identified as significant outliers (values $> \pm 2.5$ SD across the time, size and total intake measures) and significantly skewed the data. These data were removed to normalised the spread of the data. The third participant ate their breakfast just before coming into the laboratory for their beverage on one of the test days and so their data were not included. The order in which the beverages were consumed (between groups: *LE-HE* vs. *HE-LE*) was initially included in all analyses but this had no significant effect on the main outcomes and was removed from the final analyses so as to not to lose more power. Where necessary, significant main effects and interactions were interpreted using appropriate follow-up analyses, with Bonferroni adjusted *p*-values to account for multiple comparisons. All means are presented alongside the SEM and Partial Eta Squared values (η_p^2) are reported as a measure of effect size for all the analyses, indicating the portion of the variance in the outcome measures accounted for by the independent variable(s), where $\eta_p^2 \geq 0.14$ represents a large effect, $\eta_p^2 \geq 0.06$ a medium effect, $\eta_p^2 \geq 0.01$ a small effect and $\eta_p^2 \leq 0.01$ is a negligible effect (Cohen, 1988).

5.4. Results

5.4.1 Expected ‘fillingness’

Rated expectations are presented in Figure 5.4A across the sensory and labelling conditions. The expectation that the beverage would be filling was not influenced by its energy content ($F(1,41) < 0.01$, $p = .975$, $pn^2 < 0.01$) or sensory characteristics ($F(1,41) = 2.03$, $p = .162$, $pn^2 = 0.05$). Labelling did significantly affect how filling the beverage was expected to be ($F(2,41) = 3.48$, $p = .040$, $pn^2 = 0.15$) but also interacted with both sensory context and energy content to influence this judgment ($F(2,41) = 3.31$, $p = .046$, $pn^2 = 0.14$). Further analysis of this interaction indicated that when the beverages were consumed without a label, neither the energy content ($F(1,15) = 0.05$, $p = .835$, $pn^2 < 0.01$) or sensory context ($F(1,15) = 1.90$, $p = .188$, $pn^2 = 0.11$) significantly affected filling expectations, and there was no interaction between these variables ($F(1,15) = 0.096$, $p = .761$, $pn^2 = 0.01$). In the congruent label condition, energy content interacted with sensory context to influence expected filling ratings ($F(2,11) = 3.74$, $p = .079$, $pn^2 = 0.25$). This was a large effect approaching statistical significance and as Figure 5.4A suggests participants expected the HE version of the beverage labelled “Stayfull” to be more filling than the LE version labelled “Lighten”, but only when the drink had thick and creamy sensory characteristics. In the incongruent group, beverages labelled ‘Stayfull’ ($M = 66 \pm 4$) were also expected to be more filling than those labelled ‘Lighten’ ($M = 53 \pm 7$: $F(1,15) = 4.58$, $p = .049$, $pn^2 = 0.234$). However, there was no effect of sensory context in the incongruent condition, nor did these variables interact to effect expectations ($p > .270$, $pn^2 < 0.08$).

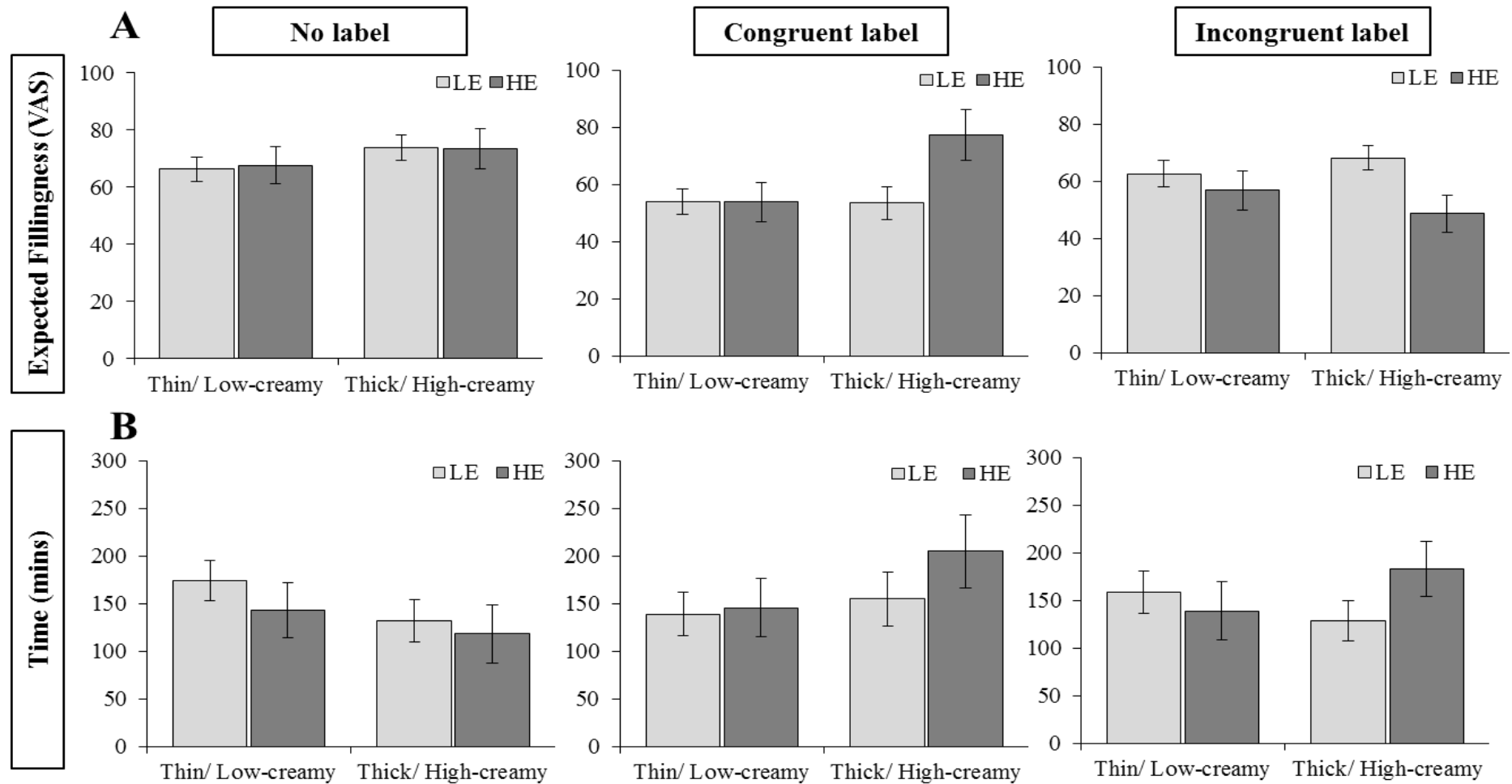


Figure 5.4 A) Expected filling ratings (VAS) B) Time taken (mins) until the first eating episode. In the congruent label condition the high-satiety label “Stayfull” was presented with the HE beverage, and the low-satiety label “Lighten” with the LE beverage. The opposite was true for the incongruent label condition. Error bars represent SEM

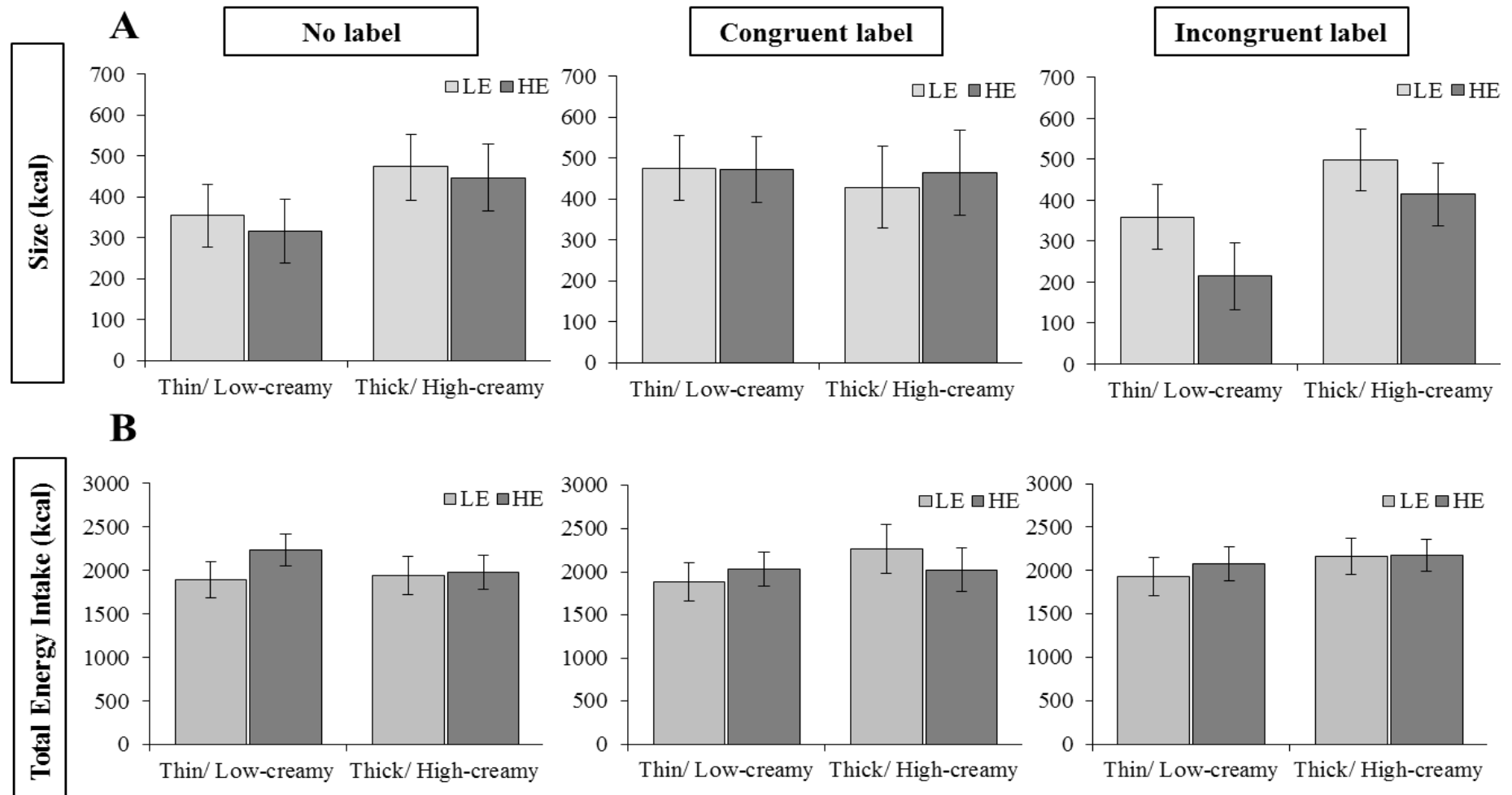


Figure 5.5 **A**) Size (kcal) of the first eating episode. **B**) Total energy intake (kcal) over the test day (including beverage). In the congruent label condition the high-satiety label “Stayfull” was presented with the HE beverage, and the low-satiety label “Lighten” with the LE beverage. The opposite was true for the incongruent label condition. All error bars represent SEM.

5.4.2 Time until first eating episode

The mean time taken until the first eating episode after consuming the beverages are outlined in Figure 5.4B. Analysis revealed no significant main effect of energy content ($F(1,41) = 0.31, p = .581, \eta^2 = 0.01$), sensory context ($F(1,41) = 0.04, p = .838, \eta^2 < 0.01$) or labelling ($F(2,41) = 0.41, p = .667, \eta^2 = 0.02$) on the time until next eating. There were also no significant interactions between these variables ($p > .271, \eta^2 < 0.06$), except the energy x sensory interaction did show a trend in-line with our previous findings ($F(2,41) = 2.60, p = .115, \eta^2 = 0.06$): participants consuming the beverages in the thin/low-creamy sensory context waited slightly longer to eat again after consuming the LE ($M = 158 \pm 13$ minutes) drink compared to the HE version ($M = 143 \pm 17$ minutes), but participants consuming the beverages in the thick/high-creamy context waited the longest to eat after consuming the HE beverage ($M = 169 \pm 19$ minutes) and the least amount of time after consuming the LE version ($M = 138 \pm 14$ minutes).

5.4.3 Size of first eating episode

Amount consumed at the first eating episode is shown in Figure 5.5A. There was no evidence that the size of the first eating episode depended on energy content ($F(1,41) = 1.08, p = .308, \eta^2 = 0.03$) or labelling ($F(2,41) = 0.91, p = .410, \eta^2 = 0.05$), but there was an unexpected trend for participants to eat more after the thick/high-creamy beverages ($M = 454 \pm 39$ kcal) compared to the thin/low-creamy versions ($M = 365 \pm 36$ kcal: $F(1,41) = 2.84, p = .100, \eta^2 = 0.07$) regardless of energy content. There were no significant interactions between variables (all $p > .321, \eta^2 < 0.05$).

5.4.4 Total energy intake over the test days

Total energy intake including the energy provided by the drink (78 kcal from the LE version and 279 kcal from the HE version, see Figure 5.5B) was not affected significantly by beverage energy content ($F(1,41) = 0.67, p = .417, \eta^2 = 0.02$), sensory context ($F(1,41) = 0.312, p = .574, \eta^2 = 0.01$) or labelling ($F(2,41) = 0.09, p = .917, \eta^2 < 0.01$), and there were no interactions ($p > .133, \eta^2 < 0.05$). These results were the same when the energy contribution from the test-drink was not included in the analysis (for all main effects and interactions: $p > .133, \eta^2 < 0.05$).

5.4.5 Percentage compensation for the additional nutrients in the HE drink

The difference in total daily energy intake after the HE compared to the LE beverage was described as percentage of the additional 201 kcal consumed in the HE version and is presented in Figure 5.6. There was no significant effect of sensory context ($F(1,41) = 2.35, p = .133, \eta^2 = 0.05$) or labelling ($F(2,41) = 0.57, p = .569, \eta^2 = 0.03$) on these percent compensation values, and these variables did not significantly interact ($F(2,41) = 0.17, p = .841, \eta^2 = 0.01$). However, it is worth noting that participants consuming the beverages in the enhanced sensory context tended to compensate for more of the energy in the HE beverage over the course of the day than those who consumed the thin and low-creamy versions, and those who consumed these beverages combined with a high-satiety label compensated the most overall (over 100%).

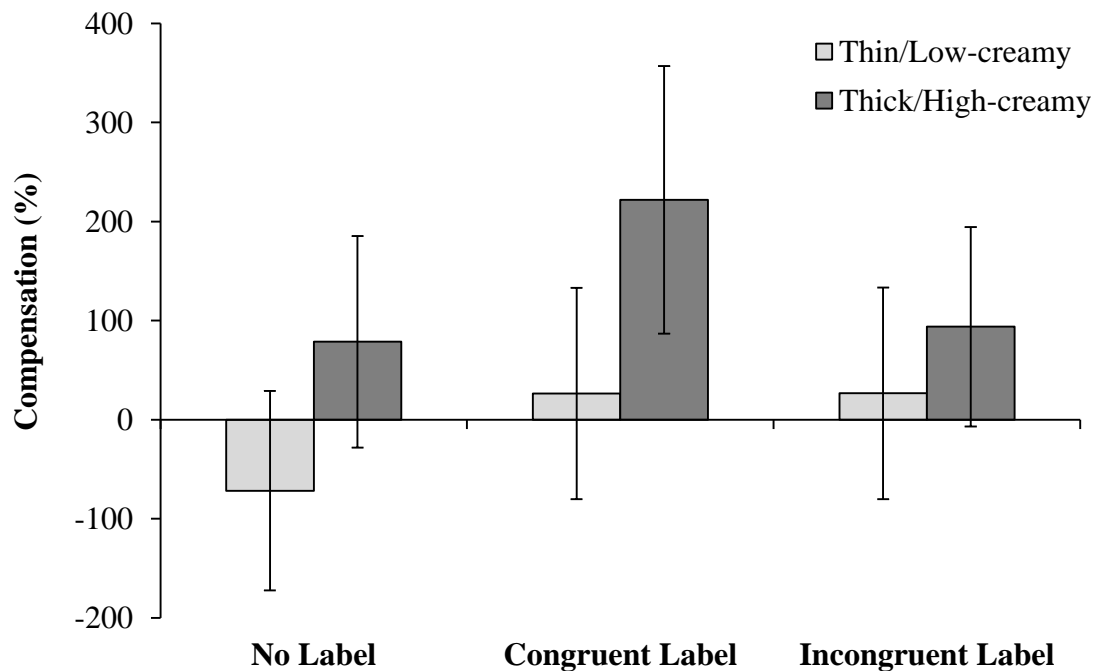


Figure 5.6. Percentage compensation for the additional energy in the HE beverages compared to the LE versions, for each of the six beverage conditions: 100% represents full compensation for the 201 kcal consumed in the HE beverage compared to the LE version, based on participants total daily energy intake. In the congruent label condition the high-satiety label was presented with the HE beverage, and the low-satiety label with the LE beverage. The opposite was true for the incongruent label condition.

Table 5.3 Appetite ratings (VAS) pre- and post-beverage for all the beverage conditions (Mean \pm SEM)

		No Label				Congruent Label				Incongruent Label			
		Thin		Thick		Thin		Thick		Thin		Thick	
		Low-creamy		High-creamy		Low-creamy		High-creamy		Low-creamy		High-creamy	
		LE	HE	LE	HE	LE	HE	LE	HE	LE	HE	LE	HE
Hunger	Pre	30 \pm 9	40 \pm 9	39 \pm 10	39 \pm 9	32 \pm 10	42 \pm 9	10 \pm 12	16 \pm 12	36 \pm 10	41 \pm 9	43 \pm 9	46 \pm 9
	Post	15 \pm 8	23 \pm 7	27 \pm 8	39 \pm 8	23 \pm 8	24 \pm 8	5 \pm 10	7 \pm 10	18 \pm 8	15 \pm 8	21 \pm 8	33 \pm 9
Fullness	Pre	54 \pm 8	41 \pm 8	41 \pm 8	56 \pm 9	59 \pm 8	56 \pm 9	61 \pm 10	55 \pm 11	60 \pm 8	57 \pm 9	54 \pm 8	47 \pm 8
	Post	80 \pm 6	81 \pm 6	85 \pm 6	88 \pm 6	73 \pm 6	75 \pm 6	69 \pm 8	87 \pm 8	77 \pm 6	79 \pm 6	82 \pm 6	71 \pm 6
Thirst	Pre	66 \pm 6	68 \pm 6	62 \pm 6	56 \pm 7	65 \pm 6	63 \pm 7	41 \pm 8	31 \pm 8	52 \pm 6	63 \pm 7	65 \pm 6	61 \pm 6
	Post	42 \pm 8	35 \pm 9	49 \pm 9	54 \pm 9	24 \pm 9	26 \pm 9	5 \pm 11	15 \pm 11	26 \pm 9	18 \pm 9	37 \pm 8	31 \pm 9

Table 5.4 Sensory and hedonic ratings (VAS) of the different test beverages (Mean \pm SEM)

		No Label				Congruent Label				Incongruent Label			
		Thin		Thick		Thin		Thick		Thin		Thick	
		Low-creamy		High-creamy		Low-creamy		High-creamy		Low-creamy		High-creamy	
		LE	HE	LE	HE	LE	HE	LE	HE	LE	HE	LE	HE
Thick		59 \pm 7	65 \pm 7	62 \pm 7	70 \pm 8	44 \pm 7	59 \pm 8	46 \pm 9	59 \pm 10	53 \pm 7	50 \pm 7	67 \pm 8	61 \pm 7
Creamy		68 \pm 6	65 \pm 7	63 \pm 7	70 \pm 8	61 \pm 7	59 \pm 8	50 \pm 9	59 \pm 10	53 \pm 7	50 \pm 8	63 \pm 6	61 \pm 7
Sweet		72 \pm 6	67 \pm 6	60 \pm 6	61 \pm 6	72 \pm 6	71 \pm 6	66 \pm 7	49 \pm 7	82 \pm 6	83 \pm 6	70 \pm 6	68 \pm 6
Pleasant		62 \pm 9	53 \pm 9	62 \pm 9	58 \pm 9	50 \pm 9	54 \pm 9	36 \pm 11	29 \pm 12	74 \pm 9	73 \pm 9	60 \pm 9	59 \pm 9
Familiar		47 \pm 9	49 \pm 9	63 \pm 9	56 \pm 10	64 \pm 9	55 \pm 10	50 \pm 12	35 \pm 12	60 \pm 9	72 \pm 10	58 \pm 9	46 \pm 9

5.4.6 Changes in rated appetite pre- to post-beverage

Changes in rated hunger, fullness and thirst pre- to post-beverage are presented in Table 5.3 for each of the drink conditions. Overall, rated hunger decreased pre-beverage ($M = 33 \pm 4$) to post-beverage ($M = 19 \pm 3$), and this was not affected by the beverage's energy content ($F(1,41) = 0.65, p = .425, \eta^2 = 0.02$), sensory characteristics ($F(1,41) = 0.79, p = .380, \eta^2 = 0.02$) or labelling ($F(2,41) = 1.05, p = .359, \eta^2 = 0.05$). There was, however, a marginally significant energy * sensory * label interaction, independent of time ($F(2,41) = 3.18, p = .052, \eta^2 = 0.13$), which reflected particularly low pre- and post-beverage hunger ratings by the participants consuming the high-sensory beverages in the congruent label condition, particularly on the LE days (see Table 5.3).

Participant's rated fullness increased from pre- ($M = 53 \pm 3$) to post- ($M = 79 \pm 2$) beverage, and this was not affected by the beverage's energy content ($F(1,41) = 1.64, p = .208, \eta^2 = 0.04$) or sensory context ($F(1,41) = 0.59, p = 0.447, \eta^2 = 0.01$) but there was evidence that the change in rated fullness pre- to post-beverage did depend on labelling ($F(1,41) = 3.02, p = .060, \eta^2 = 0.13$): closer look at this interaction revealed that rated fullness increased from pre- to post-beverage in all three labelling groups but that this effect was largest in the no label condition (no label: $F(1,16) = 51.37, p < .001, \eta^2 = 0.76$; congruent label: $F(1,12) = 20.85, p = .003, \eta^2 = 0.64$; incongruent label: $F(1,16) = 16.37, p = .003, \eta^2 = 0.51$).

Overall rated thirst decreased after consuming the beverages (pre-beverage: 58 ± 2 ; post-beverage: 30 ± 4). Significant time * energy * labelling ($F(2,41) = 4.20, p = .022, \eta^2 = 0.17$) and time * energy * sensory ($F(1,41) = 7.24, p = .010, \eta^2 = 0.15$) interactions suggested the changes in thirst over time depended on the beverage's characteristics. To look closer at these interactions separate ANOVAs comparing the beverage's energy content pre- and post-beverage were conducted across each of the label groups and the sensory contexts. This revealed that within each group thirst ratings consistently decreased pre- to post-beverage (for all main effects of time: $p < .045, \eta^2 > 0.31$), however, there was no clear evidence that this was significantly affected by the beverage's energy content (for all energy * time interactions: $p < .150, \eta^2 > 0.28$).

5.4.7 Sensory and hedonic ratings of the test drinks

The sensory and hedonic ratings are presented in Table 5.4. The drinks were designed so the thin/low-creamy drinks were perceived to be less thick and creamy than the thick/high-creamy versions, matched across energy content. But contrary to published pilot data (Yeomans & Chambers, 2011), all of the beverages in this study were perceived to be similarly thick and creamy regardless of their sensory context, and they were not affected by the beverage's energy content or labelling (for all main effects and interactions: $p = .147$, $p\eta^2 = 0.09$). The beverages were also rated as equally familiar and sweet regardless of their sensory context, energy content and labelling (for all main effects and interactions: $p = .115$, $p\eta^2 = 0.10$). Pleasant ratings were not affected by the beverages sensory context ($F(1,41) = 2.02$, $p = .163$, $p\eta^2 = 0.05$) or energy content ($F(1,41) = 0.79$, $p = .380$, $p\eta^2 = 0.02$) but was affected by labelling ($F(2,41) = 3.78$, $p = .031$, $p\eta^2 = 0.02$): the beverages in the congruent group ($M = 42 \pm 7$) were rated as less pleasant than the beverages in the incongruent label group ($M = 66 \pm 6$, $p = .028$), but these did not differ from the pleasantness of the beverages in the no label group ($M = 59 \pm 6$; $p < .221$ for both comparisons). There were no interactions affecting pleasantness ratings ($p > .413$, $p\eta^2 < 0.042$).

5.4.8 Debrief questions

At the end of the study participants were asked to interpret the purpose of the study and to comment on whether they thought using the food diary impacted their eating behaviour on the test days. Table 5.5 outlines the proportions of the participants' responses. In line with the cover story most participants thought the purpose of the study was to investigate the relationship between food and mood. A moderate proportion identified the effect of the beverage on appetite as the aim of the study, with about half specifying the role of the "label" or "advertising". A smaller proportion made other suggestions such as "investigating eating habits", "looking at BMI and diet" and "I don't know". No one identified that the two beverages they consumed (HE and LE) differed in any way.

Generally participants did not feel that completing the food diary influenced what they consumed on the test days. Of those participants who felt the diary did influence, most believed that the diary made them "more aware" of what they were consuming and

“stopped me sharing food”. Several reported snacking less to “avoid the effort” of recording. One participant reported “eating simpler foods” to help the diary records.

Table 5.5 Participant responses to the debrief questions.

What do you think was the purpose of the study?			
	Food and mood	Effect of the drink on appetite	Other
<i>N</i> = 48	<i>n</i> = 27	<i>n</i> = 15	<i>n</i> = 6
Do you think the filling out the diary affected what and/or how much food you ate?			
	No	Yes, what I ate	Yes, how much I ate
<i>N</i> = 48	<i>n</i> = 31	<i>n</i> = 1	<i>n</i> = 16

5.5 Discussion

The current study considered the extent to which the *expected* and *actual* satiating power of a caloric beverage depended on expectations generated by satiety-relevant labelling, the beverage's sensory characteristics and energy content. Key findings suggest that the beverages with the high-satiety label were expected to be more filling than those with the low-satiety version, particularly when the "Stayfull" label was presented alongside the thicker and creamier sensory context. Despite these different expectations, there was no clear influence of the beverages labelling, sensory context or energy content on changes in appetite after consumption and on subsequent energy intake. This is in part due to reduced power as a result of the smaller than intended participant numbers, and ultimately makes it difficult to draw firm conclusions from these data.

Overall the beverage's energy content appeared to have little effect on subsequent energy intake over the rest of the day. This is in line with research highlighting the particularly poor satiating effect of energy consumed in beverage form (Cassady *et al.*, 2012; Flood-Obbagy & Rolls, 2009; Mattes, 2005; Mattes & Campbell, 2009; Mourao *et al.*, 2007). However, there was some tentative evidence to show that compensation for the additional energy consumed was greatest in the thicker and creamy beverages with the high-satiety labelling, and participants consuming these beverages waited the longest time before eating again after the high-energy version. These patterns of data support our previous finding that the satiating effect of a higher-energy beverage was improved when it was consumed in a thick and creamy satiety-relevant sensory context (Bertenshaw *et al.*, 2013; Yeomans & Chambers, 2011; Yeomans *et al.*, 2014), but suggests that this effect could be further enhanced by labelled satiety messages, such as "Stayfull: keeps you fuller throughout the day", to promote greater expectations of satiety. Furthermore, these data suggest that these cognitive and sensory enhancements might impact eating behaviour outside of the laboratory setting. But while this supports the view that the development of satiety integrates the early cognitive and sensory cues generated by a food with its post-ingestive nutrient effects, this interpretation should be considered cautiously given the small participant numbers and large variation in participants' satiety responses.

Even with appropriate study power, previous research has not always identified an effect of labelled satiety-messages on behavioural measures of food intake regulation (Chambers *et al.*, 2013; Crum *et al.*, 2011; Yeomans *et al.*, 2001). For example, Crum *et al.* (2011) found that a chocolate milkshake labelled high-calorie and “Indulgent” elicited a slower decline in plasma ghrelin concentrations compared to the same milkshake labelled as a lower-calorie “Sensi-shake”. However, differences in ghrelin levels were not accompanied by changes in reported hunger or later food intake, even though higher levels of ghrelin have been linked to food anticipation (Drazen *et al.*, 2006) and increased hunger and food intake (Wren *et al.*, 2001). Possibly, studies ‘failing’ to detect an effect of labelling on behavioural indices of satiety (e.g. changes in appetite and subsequent food intake) missed relevant physiological changes by not measuring them. Nevertheless, a recent study by Hogenkamp *et al.* (2013) suggests this is unlikely, as they reported differences in later food intake in response to high- and low-calorie yogurt labels, but no differences in post-prandial hormone profiles (specifically ghrelin, insulin and cortisol).

Whether labelled satiety messages impact the actual satiating effect of a food will depend on the consumers’ interpretations of the label. The present study indicates that in one of the label groups (congruent label), interpreting the beverage labelled “Stayfull” as a filling product depended on whether the beverage also had satiety-relevant sensory characteristics. While in the other label group (incongruent label), the beverage labelled “Stayfull” was interpreted as more filling regardless of the sensory characteristics. This difference might reflect variance in the interpretation of the sensory and labelled information across the different groups of participants. Research has shown that some people find it relatively difficult to interpret labelled nutritional information, including calorie details, and many people are often sceptical of labelled health claims (Campos, Doxey, & Hammond, 2011; Vanderlee *et al.*, 2012). On the other hand, people tend to consistently expect foods and beverages with thicker and creamier sensory characteristics to be more satiating (McCrickerd *et al.*, 2012; Hogenkamp, *et al.* 2011). Thus, it is possible that satiety-relevant expectations generated by labels have the biggest impact on eating behaviour when they are believable and unambiguous, and appropriately matched to the product’s sensory characteristics and nutrient effects.

It is worth noting that the same perceptible sensory modifications to thickness and creaminess successfully used in our previous studies and pilot data (McCrickerd *et al.*, 2012; Yeomans & Chambers, 2011) appeared to be less effective in the current study. One possibility is that the rated differences were minimised because the two sensory contexts were not compared side-by-side as they were previously (participants' consumed either the thin/low-creamy *or* the thick/high-creamy context). In a similar way that the beverages' sensory characteristics appeared to influence interpretation of the labelled messages, it is possible that the labelling may have also biased the sensory and hedonic appraisal of the beverages. Provided that prior expectations are not strongly disconfirmed by the actual taste experience of a food (Yeomans, Chambers, Blumenthal, & Blake, 2008), a consumer's sensory and hedonic evaluation of a product tend to represent an assimilation of the expected and actual taste characteristics (Liem *et al.*, 2012b; Tuorila, Meiselman, Cardello, & Leshner, 1998; Wansink *et al.*, 2005b). For example, a soup with a "reduced-salt" food label was perceived as less-salty than the same soup without this label (Liem *et al.*, 2012a). Across both of the label conditions in the current study, the mean thick and creamy ratings tended to be higher when the beverage was labelled with the "*Stayfull*" rather than "*Lighten*" information. Believing the product would be filling may have biased thicker and creamier sensory ratings, because these are sensory cues associated with fullness (Hogenkamp *et al.*, 2011; McCrickerd *et al.*, 2012).

Finally, the food diary methodology was employed to test whether cognitive and sensory influences on nutrient-induced satiety translated into 'real-world' eating behaviours. Measuring free-living food intake is arguably more naturalistic and representative of real-world eating than measuring intake in a controlled laboratory setting (Bellisle & Drewnowski, 2007; Blundell *et al.*, 2010). However, the lack of control for influential environmental factors on eating behaviour, such as food availability and social cues, is likely to have compromised the sensitivity of the food intake measurement to detect effects attributed to the different beverages. Self-report measures of short-term food intake can be biased by underreporting, which is thought to be more prevalent in certain populations such as females, restrained eaters, and people who are obese, which can limit comparison of food diary records in between-subject and mixed experimental designs (de Castro, 2006; Livingstone & Black, 2003) such as the one used in this study. To minimise group differences the present study only

recruited low-retrained and non-obese healthy female participants, who were randomly assigned to a beverage condition. Most participants reported that the food diary record did not affect what and how much food they consumed over the day. Yet, just over a third reported that it did, primarily because the records were too effortful and stopped some participants snacking and sharing food. While the addition of photographic records can improve compliance and underreporting in diary records (de Castro, 2010; Kikunaga, Tin, Ishibashi, Wang, & Kira, 2007) it did appear to introduce more effort into the task, and affected records by reducing what some people consumed in certain situations. Because of small participant numbers, it was not feasible to test the effects of the beverages on intake in only those participants who did not think the diary methodology affected intake, but this effect should be considered in future work.

In summary, the present study provides some tentative evidence that both labelled satiety messages can influence the expected satiating effect of a beverage, and in combination with satiety-relevant thick and creamy sensory cues could impact upon the satiating effect of higher-energy beverages. Importantly, a low sample size and subsequent power issues means these conclusions should be treated with caution and carefully considered alongside other findings. Nevertheless, given the utilisation of product labelling by the food industry, it is important to continue investigating how label-generated satiety-relevant expectations and beliefs interact with other features of a beverage, such as sensory quality and energy content, to affect satiety and to eventually promote better energy intake regulation surrounding these products.

5.5.1 Author contributions

KMc, MRY and LC designed the study. KMc prepared the study materials, coded the food diaries, analysed the data, and drafted the manuscript. The authors would like to thank Lydia Stabels and Laura Jansz for their assistance with data collection.

Appendix 5.1

Food Diary

Test day 1.....

Test day 2.....

If found please return to Keri McCrickerd

**Pevensey 2, 4B8
Psychology Department
University of Sussex
BN1 9QG**

**Tel: 01273 872826
Email: k.mccrickerd@sussex.ac.uk**

Successfully completing your Food Diary

You should use this Diary to record **EVERY** item of food and drink that you consume over the two test days in this study. You are reminded that your specific test days and times have been recorded on the front of your diary.

Please **REMEMBER** that we are interested in your normal, everyday eating habits. In order for this to be a true reflection of your eating habits on these days, it is important that you are as **ACCURATE** and **HONEST** as possible.

Every time that you consume a **FOOD** item you should:

- Record the **time** that you ate it (start to finish).
- Record exactly **what** you ate; be as detailed as possible including brand names, restaurant names and even the recipes of any dish where ingredients are not clear.
- Record **how it was cooked** (e.g. boiled, fried in oil, salted, raw etc)
- Record as accurately as possible the **amount** that you ate, taking note of any **leftovers**. Where possible use the measuring cup supplied.
- Take a **photo** of the food item **before** it was eaten
- Take a **photo** of any **leftovers**.

*You must record your **Breakfast** every day*

Every time that you consume a **DRINK** item (excluding water) you should:

- Record the **time** that you consumed it
- Record exactly **what** you drank; be as detailed as possible including brand names.
- Record the **total volume** of the drink **consumed**.

Please try and be **ACCURATE** and **DETAILED** when recording **ALL** food and drink items in your Food Diary. The first two pages of your diary provide an example of how you should record your eating habits; you should aim to complete your diary with at least the same amount of detail. **You can use as many diary pages as you need.**

Use the **diary checklist** to:

1. Check you have recorded all food/drink items
2. Record all exercise undertaken during the recording period (other than normal daily activities such as walking home)
3. Make any additional notes

Ideally you should record all your food and drink items as you consume them throughout the day. **Your records may be less accurate if you rely on your memory** to complete your diary. However, if you do forget to record any food/drink items please record them **as soon as you remember**. If you cannot remember an item please **DO NOT** make them up!

**If you have any questions please do not hesitate to contact your
experimenter..... by email or
phone**

Thank you for taking part!

144

Date

Time (+am/pm)	Food/drink item consumed + Brand names where appropriate	Measurement	Photo (√/x)
7.30 am	<u>Breakfast</u> Toast and jam - Wholegrain toast - Salted butter - Raspberry jam (with seeds) Tea with semi-skimmed milk Orange juice	2 thick slices 2 level teaspoons 3 level teaspoons 1 cup 1 ½ cup	√
10.00 am	Fruit yogurt drink in Lab	1 bottle	
11.30 am	1 banana Black coffee + 1 sugar	medium small about 250ml	√
1.00 – 1.25 pm	Domino's pepperoni pizza 1 can Pepsi Max 1 golden delicious apple	2 slices from a large pizza 330 ml Medium	√ √
3.45 pm	Black coffee + 1 sugar Cadbury's fruit and nut chocolate bar Leftovers: ½ of bar	Small 250 ml 40 grams 20 grams	√ √
4.55 pm	½ Cadbury's fruit and nut bar	20 grams	
5.30 pm	Tea with semi-skimmed milk	1 cup	
7.30 – 9.00 pm	Red wine	2 x 175 ml glasses	
8.00 – 8.15 pm	Pasta and meat bolognaise sauce with cheese: - Sainsbury's quick cook pasta frusilli	1 ½ cups boiled in salted water	√

Time (+am/pm)	Food/drink item consumed + Brand names where appropriate	Measurement	Photo (√/x)
	<u>Breakfast</u>		
7.30 am	<i>Toast and jam</i> - Wholegrain toast - Salted butter - Raspberry jam (with seeds)	<i>2 thick slices</i> <i>2 level teaspoons</i> <i>3 level teaspoons</i>	√
	<i>Tea with semi-skimmed milk</i>	<i>1 cup</i>	
	<i>Orange juice</i>	<i>1 ½ cup</i>	
10.00 am	<i>Fruit yogurt drink in Lab</i>	<i>1 bottle</i>	
11.30 am	<i>1 banana</i> <i>Black coffee + 1 sugar</i>	<i>medium</i> <i>small about 250ml</i>	√
1.00 – 1.25 pm	<i>Domino's pepperoni pizza</i> <i>1 can Pepsi Max</i> <i>1 golden delicious apple</i>	<i>2 slices from a large pizza</i> <i>330 ml</i> <i>Medium</i>	√ √
3.45 pm	<i>Black coffee + 1 sugar</i> <i>Cadbury's fruit and nut chocolate bar</i> <i>Leftovers: ½ of bar</i>	<i>Small 250 ml</i> <i>40 grams</i> <i>20 grams</i>	√ √
4.55 pm	<i>½ Cadbury's fruit and nut bar</i>	<i>20 grams</i>	
5.30 pm	<i>Tea with semi-skimmed milk</i>	<i>1 cup</i>	
7.30 – 9.00 pm	<i>Red wine</i>	<i>2 x 175 ml glasses</i>	
8.00 – 8.15 pm	<i>Pasta and meat bolognaise sauce with cheese:</i> - Sainsbury's quick cook pasta frusilli	<i>1 ½ cups boiled in salted water</i>	√

Date

Time (+am/pm)	Food/drink item consumed + brand names where appropriate	Measurement	Photo (√/x)
9.30 pm	<ul style="list-style-type: none"> - Sainsbury's extra lean minced steak - Onion - Napolina tinned chopped tomatoes - Garlic - Red chilli - Carrot - Olive oil - Salt and pepper - Green beans <p>No leftovers</p> <p>Jasmine tea</p>	<p>83 grams ($\frac{1}{3}$ of 250 gram pack), fried</p> <p>$\frac{1}{2}$ cup, fried</p> <p>$\frac{1}{3}$ 400g tin</p> <p>1 clove, fried</p> <p>$\frac{1}{2}$ small</p> <p>1 medium, fried</p> <p>2 teaspoons for frying</p> <p>Pinch</p> <p>80 grams, Steamed</p> <p>1 large mug (2 cups)</p>	
11.30	<p>1 Satsuma</p> <p>Coco pops</p> <p>Semi skimmed milk</p>	<p>Small</p> <p>1 cup</p> <p>1 cup</p>	√

Day 1

Date

Time (+am/pm)	Food/drink item consumed + Brand names where appropriate	Measurement	Photo (√/x)
	<u>Breakfast</u>		

Check list Day 1

Did you **eat your standard breakfast** before attending the lab to receive your drink?

Yes

☐

No

☐

Have you recorded all the **food** and **drinks** consumed (excluding water) and taken a **photo** (food only)?

Tick where appropriate:

	Recorded in Diary	Photo taken
Breakfast		
Lunch		
Dinner		
All snacks		

Please make a note of any **exercise** you did throughout the day below. Be as detailed as possible.

Time (+ am/pm)	Exercise completed	Duration
<i>e.g. 4.00 pm</i>	<i>Game of squash, high intensity</i>	<i>45 min</i>

Additional notes:

Additional notes continued:

Day 2

Date

Time (+am/pm)	Food/drink item consumed + Brand names where appropriate	Measurement	Photo (√/x)
	<u>Breakfast</u>		

Check list Day 2

Did you **eat your standard breakfast** before attending the lab to receive your drink?

Yes ☐ No ☐

Have you recorded all the **food** and **drinks** consumed (excluding water) and taken a **photo** (food only)?

Tick where appropriate:

	Recorded in Diary	Photo taken
Breakfast		
Lunch		
Dinner		
All snacks		

Please make a note of any **exercise** you did throughout the day below. Be as detailed as possible.

Time (+ am/pm)	Exercise completed	Duration
<i>e.g. 4.00 pm</i>	<i>Game of squash, high intensity</i>	<i>45 min</i>

Additional notes:

Additional notes continued:

6. Paper five

Fluid or fuel? The context of consuming a beverage is important for satiety

Keri McCrickerd^{1*}, Lucy Chambers¹ and Martin R. Yeomans¹

¹ *School of Psychology, University of Sussex, Brighton, UK*

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6.1 Abstract

Energy-containing beverages have a weak effect on satiety, limited by their fluid characteristics and perhaps because they are not considered ‘food’. This study investigated whether the context of consuming a beverage can influence the satiating power of its nutrients. Eighty participants consumed a lower- (LE, 75kcal) and higher-energy (HE, 272kcal) version of a beverage (covertly manipulated within-groups) on two test days, in one of four beverage contexts (between-groups): thin versions of the test-drinks were consumed as a thirst-quenching drink ($n = 20$), a filling snack ($n = 20$), or without additional information ($n = 20$). A fourth group consumed subtly thicker versions of the beverages without additional information ($n = 20$). Lunch intake 60 minutes later depended on the beverage context and energy content ($p = .030$): participants who consumed the thin beverages without additional information ate a similar amount of lunch after the LE and HE versions (LE = 475kcal, HE = 464kcal; $p = .690$) as did those participants who believed the beverages were designed to quench-thirst (LE = 442kcal, HE = 402kcal; $p = .213$), despite consuming an additional 197kcal in the HE beverage. Consuming the beverage as a filling snack led participants to consume less at lunch after the HE beverage compared to the LE version (LE = 506kcal, HE = 437kcal; $p = .025$). This effect was also seen when the beverages were subtly thicker, with participants in this group displaying the largest response to the beverage’s energy content, consuming less at lunch after the HE version (LE = 552kcal, HE = 415kcal; $p < .001$). These data indicate that beliefs about the consequences of consuming a beverage can affect the impact of its nutrients on appetite regulation and provide further evidence that a beverage’s sensory characteristics can limit its satiating power.

6.2 Introduction

Overweight and obesity have increased worldwide (Popkin *et al.*, 2012) reflecting overconsumption relative to energetic need. This has led researchers to question whether the satiety value of foods (the extent to which a food suppresses hunger and future food intake once it has been consumed) can be improved to promote better energy regulation (van Kleef, van Trijp, van den Borne, & Zondervan, 2012). Regular ingestion of energy in beverages is thought to contribute to excessive energy intake and weight gain (Almiron-Roig *et al.*, 2013; DellaValle *et al.*, 2005; Panahi *et al.*, 2013; Rolls *et al.*, 1990b) because fluid calories have been shown to have a weak effect on satiety (Cassady *et al.*, 2012; Mattes & Campbell, 2009; Mourao *et al.*, 2007; Tournier & Louis-Sylvestre, 1991), and governments across the world are considering the ways in which population-wide consumption of these products can be reduced (Cabrera Escobar, Veerman, Tollman, Bertram, & Hofman, 2013; Fletcher, Frisvold, & Tefft, 2010; Holt, 2011). Yet beverage products are increasingly popular, with leading producers reporting record global sales in the last 10 years (Kleiman *et al.*, 2012): in the UK energy from beverages now contributes to almost a fifth of an adult's daily energy intake (Ng *et al.*, 2012). Therefore it is important to find ways to improve the satiating power of energy-containing beverages.

The development of satiety integrates early cognitive and sensory signals from a food with later post-ingestive nutrient effects (Blundell *et al.*, 2010; Blundell *et al.*, 1987). So what features of a beverage limit its satiating power and can these be changed? Research has shown that a beverage's sensory characteristics are important: beverages often fail to suppress hunger and future energy intake compared to equi-caloric solid and semi-solid versions of the same food (Cassady *et al.*, 2012; Mattes, 2006a; Mattes & Campbell, 2009; Mourao *et al.*, 2007; Tournier & Louis-Sylvestre, 1991). For example, energy consumed as apple juice was less satiating than the same nutrients consumed as apple puree, which was in-turn less satiating than apple slices (Mattes & Campbell, 2009). This could be because liquids are consumed faster than more viscous food forms which reduces the duration of oro-sensory exposure (Hogenkamp *et al.*, 2012b; Zhu *et al.*, 2013; Zijlstra *et al.*, 2008). A low viscosity but high-energy beverage requires little oro-sensory processing and this might limit its anticipated satiating effect (Hogenkamp *et al.*, 2011; McCrickerd *et al.*, 2012) and elicit inadequate anticipatory

physiological responses (such as cephalic phase salivation and gut-peptide release), which together might weaken the satiating effect of the nutrients it contains (Cassady *et al.*, 2012; Woods, 2009). Indeed, recent research from our laboratory suggests that the actual satiating power of a higher-energy beverage depended on its sensory context (Bertenshaw *et al.*, 2013; Chambers *et al.*, 2013; Yeomans & Chambers, 2011; Yeomans *et al.*, 2014). When participants consumed flavour-matched higher- and lower-energy versions of a thin beverage mid-morning they felt equally full and consumed similar amounts at lunch after both drinks, despite consuming 200 kcal extra in the higher-energy version. But when the two versions of the beverage were made to taste subtly thicker and creamier (without adding any extra energy) participants felt fuller and ate significantly less at lunchtime after they consumed the higher-energy version. Importantly, a reduction in lunch intake was not seen after the sensory-enhanced lower-energy beverage, indicating that this was not a general effect of enhanced sensory context on satiety, but a sensory-nutrient interaction where thick and creamy sensory cues only improved satiety when they predicted the delivery of nutrients. Thus, nutritive beverages may have a weak effect on satiety responses if they lack appropriate sensory cues signalling the delivery of nutrients.

Energy-containing beverages may also have a weak effect on satiety if they are not consumed in the context of ‘food’. For example, presenting a liquid as a soup suppressed hunger more than the same liquid consumed as a beverage (Mattes, 2005, 2006a; Tournier & Louis-Sylvestre, 1991). Whilst ‘eating’ a liquid with a spoon might influence satiety by increasing oro-sensory exposure time during consumption (Hogenkamp *et al.*, 2010) this may also heighten beliefs that a food is being consumed, compared to drinking the liquid which may be associated more with thirst (Wansink *et al.*, 2010). On the other hand, meal-replacement ‘shakes’ are drank like a beverage but marketed and consumed as a ‘meal’ rather than as a ‘drink’, and when consumed in this context have been shown to promote weight loss (Heymsfield *et al.*, 2003). Indeed, experimental studies indicate that satiety-related beliefs are important for appetite control (Capaldi *et al.*, 2006; Martens & Westerterp-Plantenga, 2012; Pliner & Zec, 2007). For example, participants ate more at a test meal after consuming a food perceived to be a *snack* compared to participants who consumed the same food but believed it to be a *meal* (Capaldi *et al.*, 2006). This may be because a meal is associated with greater satiety and so foods consumed in this context are expected to be more

satiating than the same foods consumed as a snack. Importantly, beliefs about the satiating effects of food can influence the actual experience of satiety: in one study participants reported feeling more full and less hungry after consuming the same smoothie believed to contain a large compared to a small portion of fruit (Brunstrom *et al.*, 2011) whilst in another study consuming a liquid with the expectation that it would solidify in the stomach (but that actually remained a liquid) elicited slower gastric-emptying and enhanced the experience of satiety (Cassady *et al.*, 2012). With these previous findings in mind, an energy-containing beverage consumed in the context of a snack might be expected to be more satiating than the same beverage consumed in a less satiety-relevant context, such as a drink. Generating beliefs of this kind might be one way to influence the satiating power of nutrients consumed as a beverage without the need to modify its sensory characteristics, which could be unacceptable to consumers.

To test this idea, participants in this study consumed a higher- and lower-energy version of a fruit-juice based beverage presented in one of four contexts varying in textural and cognitive cues: *thin texture* with no additional context information; thin texture presented as a new “*thirst-quenching beverage*”; thin texture presented as a new “*filling snack*”; *thick texture* with no additional information. The subtly thicker versions were intended as a positive control to detect the sensory-enhanced satiety reported in our previous findings (Bertenshaw *et al.*, 2013; Chambers *et al.*, 2013; Yeomans & Chambers, 2011; Yeomans *et al.*, 2014), allowing for the comparison between changing satiety-relevant beliefs and the alternative approach of modifying textural cues to influence sensitivity to nutrients consumed in a beverage. The beverage’s energy content was covertly manipulated. It was predicted that participants who consumed the thin versions of the beverage with either no information or in the context of it being a thirst-quenching drink would not respond to the covert energy difference between the beverages by adjusting their intake at a later lunch-time meal, while those who received the beverage presented as a filling snack or with added satiety-relevant sensory cues would adjust their lunch intake depending on the beverages energy content.

6.3 Materials and Methods

6.3.1 Ethics statement

This research was approved by the University of Sussex Life Science Research Ethics Board and all participants gave written informed consent to take part.

6.3.2 Design

A two-factor 4 x 2 mixed design was used to assess the satiety value (as measured by changes in rated appetite and intake at a later meal) of a beverage presented in one of four cognitive and sensory *beverage contexts* (measured between-groups: thin/no-information; thin/thirst-quenching: thin/filling; thick/no-information) varying in *energy content* (measured within-groups: lower-energy (LE) vs. higher-energy (HE)). Our previous research identified a large interactive effect of beverage energy and sensory context on later intake (Yeomans *et al.*, 2014) (power = 0.85 to detect effect size $f = 0.53$). Based on this, a sample size calculation for a mixed ANOVA design, where the effect of the cognitive manipulation was unknown but assumed to be smaller (effect size $f = 0.25$, power = 0.95) suggested 64 participants for the study ($n = 16$ in each group) which was increased to 20 per group ($n = 80$) to allow for counterbalancing and any exclusions.

6.3.3 Participants

Eighty female participants were recruited to take part in a study investigating ‘Food and Mood’ from a volunteer database held by the University of Sussex Ingestive Behaviour Unit (SIBU). Eligible participants were non-smokers, not diagnosed with an eating disorder, without allergies or aversions to any of the test food ingredients and not taking prescription medication or currently dieting. Participants were non-obese and did not have a restrained eating style as measured by a score of ≤ 7 on the Three Factor Eating Questionnaire (TFEQ), where a score of ≤ 7 out of the maximum 21 was considered as low-restrained (Stunkard & Messick, 1985). Participants were randomly assigned to one of the four beverage context groups, which did not statistically differ in mean age (years), BMI (kgm^{-2}), TFEQ-Restraint score (representing the tendency to restrict food intake) and TFEQ-Disinhibition score (representing the tendency to overeat, where scores range from 0 (low-disinhibition) to 16 (high-disinhibition)) (see Table 5.1).

Table 6.1 Mean (\pm SD) Age (years), BMI (kgm^{-2}), TFEQ Restraint and TFEQ Disinhibition scores for the participants in the different beverage context groups.

	Thin No information	Thin Thirst-quenching	Thin Filling	Thick No information	<i>p</i> -value *
Age	21 \pm 2	20 \pm 2	20 \pm 2	21 \pm 5	.809
BMI^a	22 \pm 3	23 \pm 3	22 \pm 2	23 \pm 4	.850
TFEQ-R	3 \pm 2	3 \pm 2	3 \pm 2	3 \pm 2	.949
TFEQ-D	6 \pm 3	6 \pm 2	6 \pm 4	7 \pm 3	.958

* The *p*-value from a one-way between-groups ANOVA comparing each of the demographic measures across the 4 test-groups.

^a A BMI of <18 kgm^{-2} is classed as underweight, 18-25 kgm^{-2} healthy, 25-30 kgm^{-2} overweight and 30+ kgm^{-2} obese

6.3.4 Test foods and drink

On each test day all participants consumed a standard breakfast in the lab, followed by the test drink and later an *ad libitum* lunch. They received a 500 ml bottle of spring water (Sainsbury's, UK) to drink in between these sessions. Breakfast consisted of cereal ("Crunchy Nut Cornflakes", Kelloggs, UK: 60g), semi-skimmed milk (Sainsbury's, UK: 160g) and orange juice (Sainsbury's, UK: 200g), which provided 440 kcal. Participants also consumed an *ad libitum* lunch in the lab, served in 450g portions consisting of 250g cooked conchiglie pasta combined with 200g fresh tomato and basil pasta sauce (both Sainsbury's, UK). Each portion contained 544 kcal.

The four test drinks were developed in-house based on a recipe described in a previous study (McCrickerd *et al.*, 2012) using commercially available ingredients. A higher-energy (HE) and lower-energy (LE) version of a thin and thick drink were prepared as a 320g portion, each containing fresh mango, peach and papaya fruit juice (LE and HE = 100g; Tropicana Products, Inc.), 0.1% fat fromage frais (LE = 55g, HE = 30g; Sainsbury's UK), water (LE = 130g, HE = 100g;) and peach flavoured diluting drink (LE and HE = 11g; 'Robinsons' from Britvic, UK). The HE versions of the drink also contained 55g of maltodextrin (Cargill, UK) such that one portion of the HE drink

contained 272 kcal while the LE version contained 75 kcal. A small quantity of aspartame (0.03g; Ajinomoto, Japan) was added to the LE drinks to match sweetness to the HE versions. Tara gum (Kalys Gastronomie, FR) was used to subtly increase the viscosity of the thick drinks and to match for the slight increase in viscosity caused by the addition of maltodextrin to the HE versions (thin LE = 0.2g; thin HE = 0.0g; thick LE = 1.2g; thick HE = 1.0g). Rheological measurements were conducted at 5°C on a Bohlin Rotational Rheometer at shear rates 0.1-800 s⁻¹ using parallel plate geometry (60 mm diameter) and a gap size of 1.0 mm (Malvern Instruments Ltd.). Perceived thickness of a fluid containing a similar polysaccharide thickener (guar gum) was reported to most strongly correlate with viscosity measured at shear rates of ≈ 80 -700 s⁻¹ (Koliandris *et al.*, 2010) and at these speeds the thicker drinks were more viscous than the thin versions and the high and low energy drinks were well matched, see Figure 6.1. Colour was matched between all the drink samples by small additions of natural food colouring. In our previous studies participants rated the drinks to be equally pleasant and sweet, the thicker drinks as significantly thicker and creamier than the thin versions, and were unaware of the energy manipulation (McCrickerd *et al.*, 2012; Yeomans *et al.*, 2014).

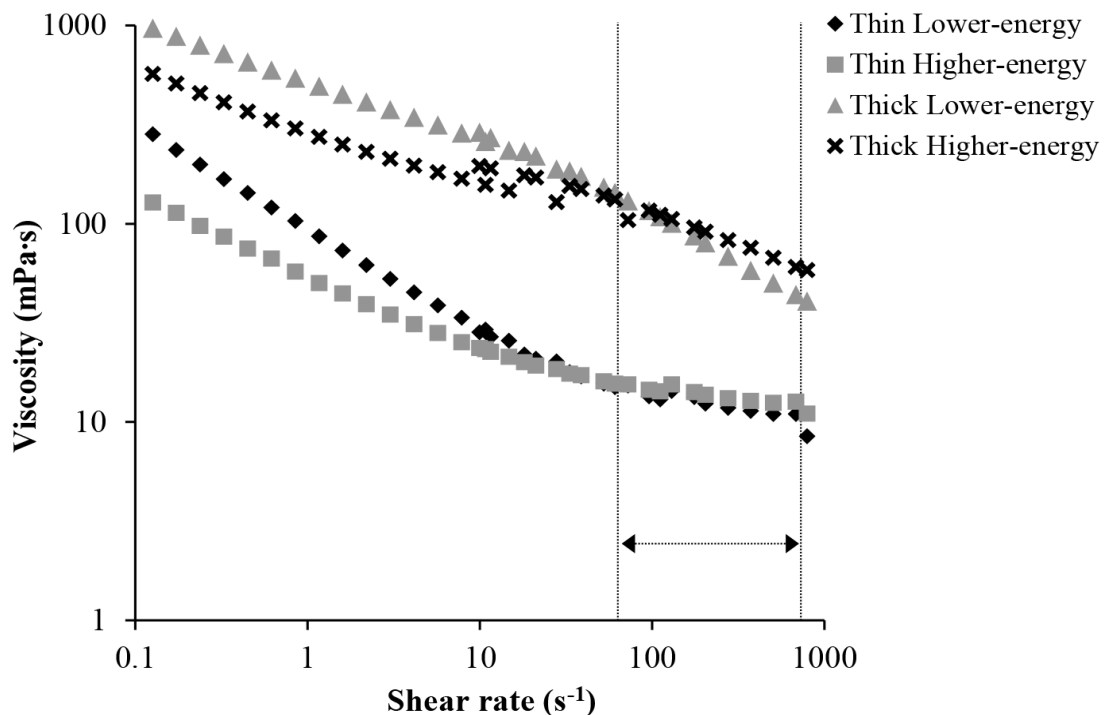


Figure 6.1 Viscosity of the four test drinks under shear. The section marked with an arrow represents viscosity measured between shear rates 80-700 s⁻¹, which are thought to best represent speeds associated with the perceived viscosity of fluids (Koliandris *et al.*, 2010).

6.3.5 Beverage context

Participants consumed higher- and lower-energy versions of the beverage in one of the four drink context conditions. One group consumed thin versions of the beverage with no additional information (*thin/no-information* group). Two more groups consumed the same thin beverages but with some additional contextual information and were informed during the first session that they would consume a new product that had been designed by a food and drink company. The *thin/thirst-quenching* group were told that they would be trying a new drink product designed to affect feelings of thirst, whereas participants in the *thin/filling* condition were told they were trying a new snack, which would affect feelings of hunger and fullness. The final group consumed thicker versions of the beverage without any additional information (*thick/no-information* group). All participants were informed that they would consume the *drink/snack* and evaluate it alongside their mood. In the two information groups participants were also presented with an information sheet “from the manufacturer” to standardise the information they received about the beverages, see Table 6.2. All the drinks were presented and consumed from a clear, pre-sealed plastic bottle using a straw.

Table 6.2 A description of the information provided to participants in the *thin/thirst-quenching* and *thin/filling* beverage context groups.

A refreshing drink to quench your thirst	A filling snack to keep hunger away
This is a drink that has been developed to stop you from feeling thirsty and to keep you hydrated throughout the day	This is a snack that has been developed to stop you from feeling hungry and to keep you full throughout the day
Drinking enough is an important part of our diet which helps our body to work properly through the day. When you don't drink enough you can become dehydrated and this can affect how you feel. If you are dehydrated you might start to feel thirsty	Eating enough is an important part of our diet which helps our body to work properly through the day. When you don't snack on the correct foods you can become hungry and this can affect how you feel. If you have not eaten enough, you might start to feel hungry

6.3.6 Procedure

Figure 6.2 summarises the main procedure and measurement points throughout the test days. Participants attended the SIBU on two non-consecutive days, arriving for breakfast at a scheduled time between 8:30 and 10:30 having consumed nothing but water from 23:00 the evening before. Once they had consumed all of their breakfast, participants left the laboratory for three hours and were instructed to consume only water in this time. They were given a 500ml bottle of water to take away and instructed to drink from this if needed and to bring the bottle back for the next session when it would be topped up. Water intake was covertly measured.

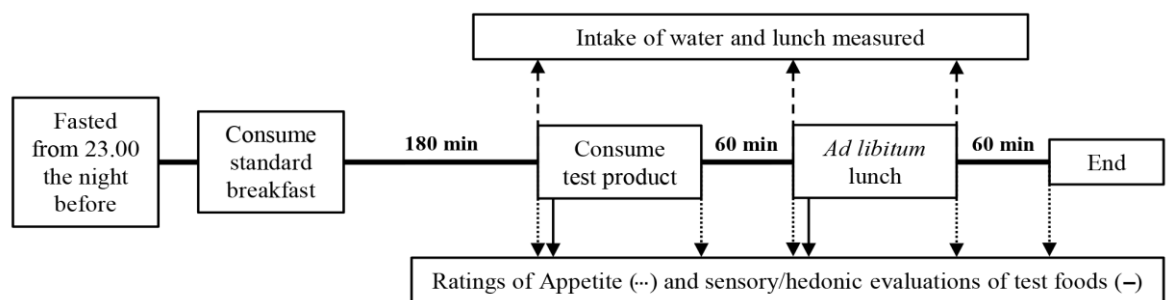


Figure 6.2 Schematic summary of the test day procedure.

After three hours participants were shown to a testing cubicle with a PC computer running the Sussex Ingestion Pattern Monitor software (SIPM: University of Sussex; Yeomans, 2000). To begin this part of the session, participants completed a set of appetite ratings called “Mood Questions” (pre-drink appetite). They were asked “How <target> do you feel right now?” and instructed to indicate the extent to which they felt *hungry*, *full* and *thirsty* by placing a marker along a 100 mm Visual Analogue Scale (VAS). The scale response ranged from “Not at all <target>” (0) to “Extremely <target>” (100) and these ratings were embedded amongst distracter “mood” ratings of *tired*, *happy*, *headachy*, *anxious*, *energetic*, *nauseous* and *alert*. All VAS ratings were presented in a randomised order and only the appetite ratings were analysed. Having completed these ratings all participants received the test-drink and, depending on their beverage context condition, they were given additional information regarding their “*drink*” or “*snack*” product. All participants were then instructed to taste the product using the straw provided and evaluate how *thick*, *creamy*, *pleasant*, *sweet* and *familiar* it was, using the same randomised VAS format as the appetite ratings. They were then asked to consume all of the drink/snack and complete a second set of “mood” questions

(post-drink appetite ratings). Once they had finished participants received their refilled bottle of water and were asked not to consume anything but water while they waited for their lunch session.

Returning to a test cubicle 60 minutes later, participants began lunch by handing in their water bottle to be topped-up and completing the third set of “mood” questions (60 minute appetite). The 60 minute time gap was based on unpublished pilot data investigating the effects of the test drink’s energy content on changes in rated appetite over 120 minutes post-consumption ($n = 49$), which indicated an effect of beverage energy content on subjective appetite from 60 minutes onwards in a similar participant population (i.e. non-dieting females reporting low dietary restraint). The time frame of a cognitive effect was unknown, but previous research has indicated that satiety-relevant beliefs can influence rated appetite 15-240 minutes after consumption and intake of another meal after 240 minutes (Cassady *et al.*, 2012). Lunch intake was measured using a concealed balance (Sartorius model BP4200) linked to the SIPM, which was secured under a placemat and covertly measured and recorded lunch intake. At the beginning of the lunch phase participants were presented with a sample of their pasta lunch and prompted to taste and rate how *familiar*, *pleasant* and *salty* it was and then asked again to rate how *hungry*, *full* and *thirsty* they felt (pre-lunch appetite). Next, they were given a 450g serving of the pasta lunch that was placed on the placemat and both the experimenter and on-screen instructions explained that they could eat as much as they liked and would receive refills when needed. After 350g had been consumed an alert sounded and they were instructed that a refill was required, at which point the researcher presented another 450g serving of pasta. Participants could end the consumption phase by selecting ‘meal terminated’ when ready, unless they were at a refill stage in which instance they would have to receive their refill first. This was to limit using the refill as a reason to end the meal. The refill procedure also prevented participants from completely finishing the portion in the bowl, another strong external cue for meal termination. Participants completed a final set of mood questions (post-lunch appetite) to end the lunch session. Participants were asked to not eat or drink anything but water for another hour after lunch in order to limit the potential for the future availability of food to influence lunch intake decisions. They completed a paper version of the mood questions at the end of this hour that was returned at the start of the next session but these data are not reported.

Overall participants completed two test days that were identical except for the energy content of the test beverage. Participants received the LE beverage in one session and the HE version in the other, the order of which was counter-balanced within the four beverage context groups. At the end of the second day participants completed a debriefing questionnaire, after which the purpose of the study was explained and participants were asked to keep this information confidential. Height and weight measurements were recorded and participants had the opportunity to ask any questions before being thanked and receiving £20 for taking part. Compliance to eating and drinking restrictions outside of the laboratory was measured through participant self-report.

6.3.6 Debrief questionnaire

The debriefing questionnaire was used to check that all participants were naive to the true purpose of the study and to determine whether those given extra information believed the drinks were designed to be filling/thirst-quenching products. This short questionnaire first asked participants to comment on the purpose of the study (question 1) and then to identify whether they expected the products they consumed to be ‘thirst-quenching’, ‘filling’, ‘both’, ‘neither’ or ‘other’ and to give a reason for their answer (question 2). This was followed by a short series of other questions about their experience of consuming each of the test-foods over the two days (e.g. “Did you think the breakfast/drink product/lunch you consumed was the same on each day? If not, why?”). All questions required a yes/no/unsure answer and an explanation where necessary. Once this sheet was complete participants were verbally debriefed. Participants in the filling/thirst-quenching beverage context groups were then asked whether they believed that a food company had developed the drink/snack they received and their response was noted. It was assumed that participants believed the cognitive manipulations if they a) reported that they expected the drink to be thirst-quenching/filling (in line with their condition) in response to questions 1 and 2 of the debrief sheet and b) indicated that they believed they had consumed a new product from a food company. In-line with these criteria data from four participants were excluded from the final analyses.

6.3.7 Data analysis

Since the main aim of the study was to assess the extent to which satiety generated by energy consumed in a drink depended on the cognitive and sensory context in which it was presented, a series of mixed-ANOVAs were used to test the effect of the *beverage context* (between-groups: *thin/no-information* vs. *thin/thirst-quenching* vs. *thin/filling* vs. *thick/no-info*) and *energy content* manipulation (within-groups: *LE* vs. *HE*) on the key outcome measures of total lunch intake (kcal) and changes in rated appetite, with *rating time* (within-groups: *pre-drink*, *post-drink*, *60 min later*, *pre-lunch* and *post-lunch*) as an additional factor to these analyses. For the lunch intake values, the difference in lunch intake after the HE compared to the LE beverage was calculated as a percentage of the 197 kcal difference between the HE and LE versions. This describes the degree to which participants responded to the additional energy in the HE beverage (197 kcal). A similar ANOVA design was used to analyse the additional variables of water intake throughout the sessions (g) and the sensory and hedonic evaluations of the test foods.

The order in which the beverages were consumed (between groups: *LE-HE* vs. *HE-LE*) was initially included in all analyses but this had no significant effect on the main outcomes and was removed from the final analyses. All follow-up analyses used to interpret, where necessary, the direction of any main effects and interactions between the energy content and beverage context report Bonferroni adjusted *p*-values to account for multiple pairwise comparisons performed. When the assumption of sphericity was violated (within-group variable only) the appropriate Greenhouse-Geisser ($\epsilon < 0.75$) or Huynh-Feldt ($\epsilon > 0.75$) corrected degrees of freedom and *p*-values are reported. Means and SEM are presented throughout results and in figures and tables. Partial eta squared values (η_p^2) are reported as a measure of effect size for all the main analyses, and indicate the portion of the variance in the outcome measures accounted for by the independent variable(s) (a smaller value indicates a smaller amount of variance). As a general guide $\eta_p^2 \geq 0.14$ represents a large effect, $\eta_p^2 \geq 0.06$ a medium effect, $\eta_p^2 \geq 0.01$ a small effect and $\eta_p^2 \leq 0.01$ is a negligible effect (Cohen, 1988).

During the debrief two participants reported controlling their lunch intake (one was following a diet to gain weight and another reported restricting intake) and their data were excluded in addition to the four participants removed because they did not believe

the information manipulation. Therefore data from 74 participants was included in the final analyses (thin/no-information, $n = 19$; thin/thirst-quenching, $n = 17$; thin/filling, $n = 19$; thick/no-information, $n = 19$). The outcome of the main findings reported in this manuscript were not affected by including data from those participants who were excluded based on their belief in the cognitive manipulation.

6.4 Results

6.4.1 Lunch intake

Participants consumed significantly less of the pasta lunch overall after having the HE drink compared to the LE version ($M_{HE} = 429 \pm 19$ kcal, $M_{LE} = 494 \pm 18$ kcal: $F(1, 70) = 17.82, p < .001, \eta_p^2 = 0.20$). There was no overall effect of the beverage's context on lunch intake ($F(3, 70) = 0.63, p = .598, \eta_p^2 = 0.03$) but this did interact with energy content to influence lunch intake ($F(3, 70) = 3.15, p = .030, \eta_p^2 = 0.12$; see Figure 6.3). Looking at the effect of energy content within each beverage context, those who consumed the thin beverage with no additional information (*thin/no-information*) consumed a similar amount of lunch after the HE and LE versions ($F(1, 70) = 0.16, p = .690$) despite consuming almost 200 extra kcal in the HE drink. Similarly, those participants who consumed the thin drink and believed it to be thirst-quenching (*thin/thirst-quenching*) did not significantly differ in the amount they consumed after the HE and LE drink ($F(1, 70) = 1.58, p = .213$). In contrast, participants who consumed the drink in the context of a snack (*thin/filling*) consumed significantly less after the HE drink compared to the LE version ($F(1, 70) = 5.25, p = .025$). The largest difference in lunch intake after the HE drink compared to the LE version was seen in the *thick/no-information* group who consumed the beverage in the thick sensory context ($F(1, 70) = 20.69, p < .001$).

The difference in lunch intake after the LE compared to the HE beverage was described as percentage of the additional 197 kcal consumed in the HE version. This indicated that the difference in lunch intake after the LE compared to HE beverage for the *thin/no-information* group equated to 6 % of the additional energy in the HE version. In the *thin/thirst-quenching* and *thin/filling* groups this increased to 20% and 35% of the additional energy respectively, while participants in the *thick/no-information* group responded the most, showing a difference in lunch intake that accounted for 70% of the extra energy consumed.

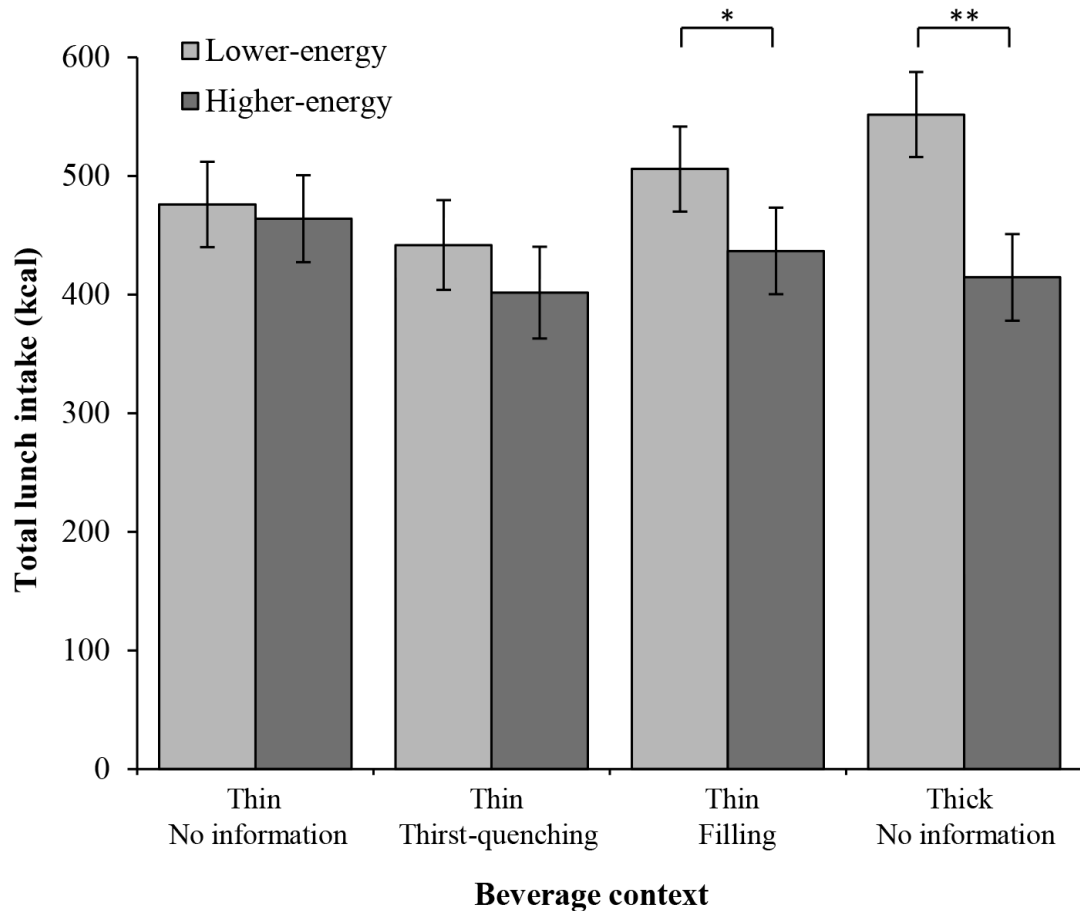


Figure 6.3. Mean lunch intake (\pm SEM) after consuming both the lower-energy and higher-energy versions of the drinks across each group, * indicates a significant difference where $p > .05$ and ** $p > .001$.

6.4.2 Changes in rating appetite

Changes in hunger, fullness and thirst ratings throughout the test days are presented in Figure 6.4. Rated hunger decreased immediately after consuming all drinks, increasing back towards original levels before lunch, and decreasing again after lunch was consumed ($F(3,244) = 325.51, p < .001, \eta_p^2 = 0.82$). The reverse was seen with fullness ratings ($F(4,256) = 342.76, p < .001, \eta_p^2 = 0.83$). Furthermore, changes in rated hunger over time depended on the energy content of the beverage ($F(3,239) = 3.31, p = .016, \eta_p^2 = 0.05$) as the HE drinks suppressed hunger more than the LE drinks in the interval between consuming the drink and eating the pasta. This was the same across the four beverage contexts ($F(10,239) = 0.62, p = .798, \eta_p^2 = 0.03$). There was also a trend for the HE drinks to increase fullness in the period before lunch more than the LE drinks, which was primarily for those consuming the drinks in the thin/thirst-quenching beverage context ($F(12,278) = 1.68, p = .072, \eta_p^2 = 0.07$; see Figure 6.4). The main

effect of drink condition on hunger and fullness ratings and all other interactions were non-significant ($p \geq .134$, $\eta_p^2 \leq 0.06$). Ratings of thirst also changed over time ($F(3,241) = 19.80$, $p < .001$, $\eta_p^2 = 0.22$): thirst decreased immediately after consuming the drink, and then increased over the next 60 minutes. There was no significant effect of drink energy on thirst ratings ($F(1,70) = 1.27$, $p = .264$, $\eta_p^2 = 0.02$) nor did the drink's energy content influence changes in thirst over time ($F(4,259) = 0.66$, $p = .612$, $\eta_p^2 = 0.01$). However, there was evidence that the beverage context interacted with beverage energy content to influence thirst ratings overall ($F(3,70) = 3.28$, $p = .026$, $\eta_p^2 = 0.12$), with participants in the *thin/filling* groups reporting being more thirsty on the HE day compared to the LE day ($p = .007$) whereas there was a trend for the opposite in the *thin/thirst-quenching* group ($p = .098$). Participants in the thin and thick *no-information* groups reported being similarly thirsty across the HE and LE drinks days ($p \geq .362$). No other effects or interactions were significant ($p \geq .612$, $\eta_p^2 \leq 0.03$).

6.4.3 Water-intake

The amount of water participants consumed during the test days differed depending on the time of day ($F(2,140) = 53.39$, $p < .001$, $\eta_p^2 = 0.43$): participants tended to consume slightly less during lunch ($M = 202 \pm 11$ g) than in the 3 hour gap between breakfast and the test drink ($M = 238 \pm 14$ g, $p = .052$), and the least in the 60 minute gap between the drink and lunch ($M = 99 \pm 11$ g; $p > .001$ for both comparisons). There was no evidence that water intake after consuming the test drink was different depending on the beverage context ($F(6,140) = 0.90$, $p = .496$, $\eta_p^2 = 0.04$) or energy content ($F(2,129) = 0.698$, $p = .488$, $\eta_p^2 = 0.01$). There were no other interactions or main effects ($p \geq .440$, $\eta_p^2 \leq 0.04$).

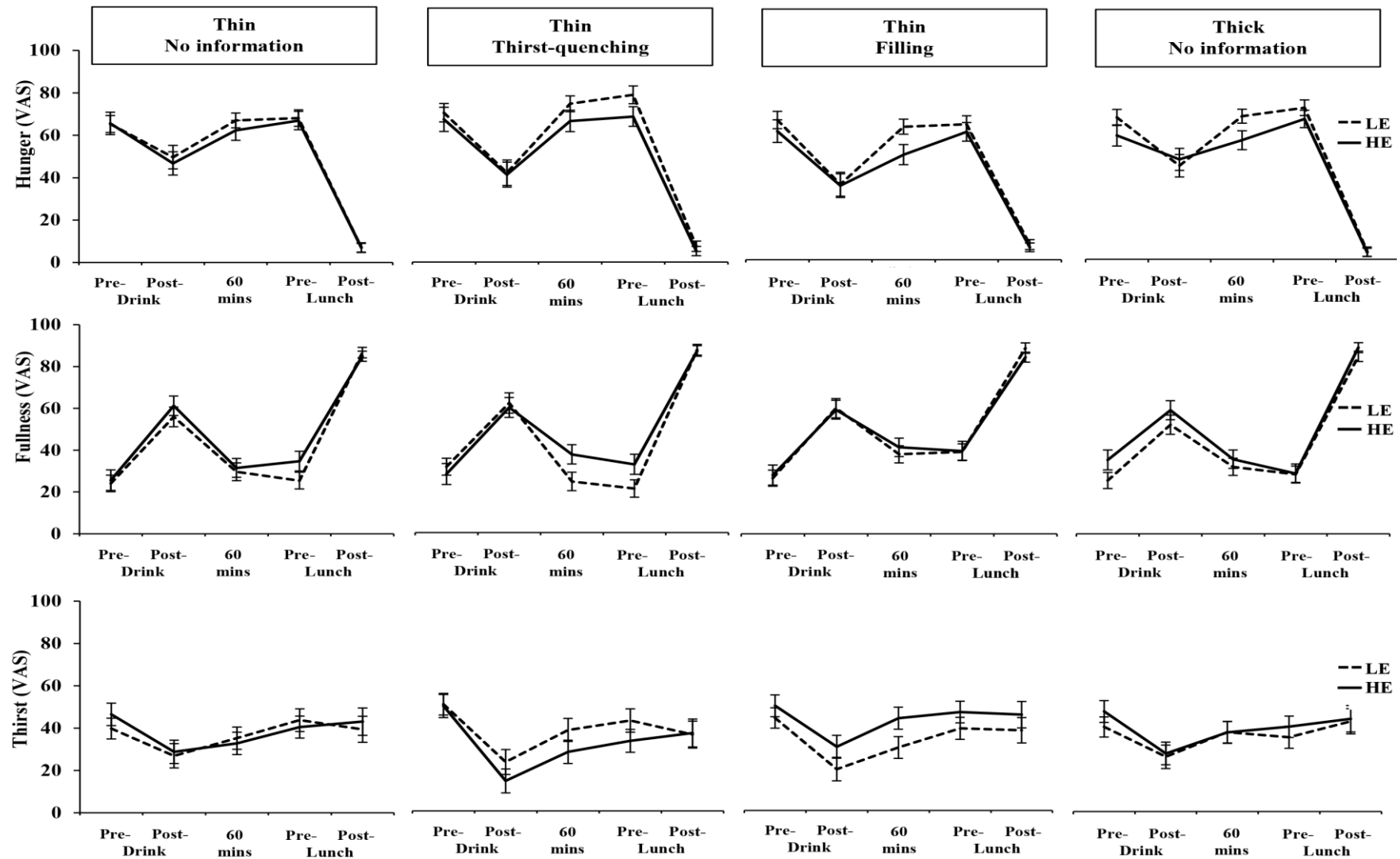


Figure 6.4 Hunger, fullness and thirst VAS ratings pre- and post-drink, 60 minutes later, pre-and post-lunch, across each drink context.

6.4.4 Sensory ratings of the test products

The drinks were designed so that the thick LE and HE versions (used in the *thick/no-information* context) were perceived to be thicker and creamier than the thin LE and HE versions (used in the three thin contexts: *no-information*, *thirst-quenching* and *filling*). The mean sensory and hedonic ratings for the test drinks are presented in Table 6.3. Perceived thickness did differ across the four beverage contexts ($F(3,70) = 3.34$, $p = 0.024$, $\eta_p^2 = 0.13$): the thick drinks were rated as thicker than the thin drinks consumed in the *thirst-quenching* context but not compared to the thin drinks consumed in the *no-information* or *filling* contexts. While there was no overall effect of energy content on rated thickness ($F(1,70) = 0.05$, $p = .818$, $\eta_p^2 < 0.01$), a beverage context by energy content interaction suggested that the HE drinks were rated as subtly thicker than the LE versions in the thin/thirst-quenching group, but not in any other beverage context ($F(3,70) = 3.18$, $p = .029$, $\eta_p^2 = 0.12$; see Table 6.3). Rated creaminess also differed between beverage context groups ($F(3,70) = 3.75$, $p = .015$, $\eta_p^2 = 0.14$) following the same pattern as the thickness ratings: the thicker drinks were rated as creamier than the thin drinks consumed in the *thirst-quenching* context only. Beverage context did not interact with energy content to influence creaminess ratings ($F(3,70) = 0.28$, $p = .838$, $\eta_p^2 = 0.01$), but there was an overall effect of energy content ($F(1,70) = 5.43$, $p = .023$, $\eta_p^2 = 0.07$) with the LE drinks rated as slightly creamier than the HE versions (see Table 6.3). As for the rated pleasantness of the drinks, this depended on the beverage context and energy content ($F(3,56) = 3.47$, $p = .021$, $\eta_p^2 = 0.13$): although both versions were rated highly, the thick LE drink was rated as more pleasant than the thick HE drink while there was a trend for the opposite in the thin/thirst-quenching group (see Table 6.3). The LE and HE versions did not differ in rated pleasantness in any of the other thin beverage context groups. There was no main effect of beverage context or energy content on rated pleasantness ($p \geq .384$, $\eta_p^2 \leq 0.04$ for both main effects). Otherwise, the drinks were all rated as similarly sweet and familiar (for all main effects and interactions $p \geq .356$, $\eta_p^2 \leq 0.05$).

Participants rated the pasta lunch as similarly pleasant across the test sessions and these ratings did not depend on the beverage context or energy content ($p \geq .155$, $\eta_p^2 \leq 0.07$ for each main effect and the interaction). The pasta lunch was also rated as similarly familiar and salty ($p \geq .102$, $\eta_p^2 \leq 0.08$ for all main effects and interactions).

Table 6.3 Mean (\pm SEM) sensory ratings of the higher- and lower- energy test drinks in each beverage context condition.

		Thin No information	Thin Thirst- quenching	Thin Filling	Thick No information
Thick^a	LE	67 \pm 4	55 \pm 4	63 \pm 4	75 \pm 4
	HE	67 \pm 4	63 \pm 5	61 \pm 4	73 \pm 4
Creamy^b	LE	66 \pm 4	61 \pm 4	67 \pm 4	77 \pm 4
	HE	61 \pm 5	53 \pm 5	65 \pm 5	72 \pm 5
Sweet^c	LE	74 \pm 3	73 \pm 3	73 \pm 3	71 \pm 3
	HE	77 \pm 3	70 \pm 3	71 \pm 3	73 \pm 3
Familiar^c	LE	69 \pm 5	65 \pm 5	64 \pm 5	67 \pm 5
	HE	75 \pm 5	58 \pm 6	68 \pm 5	72 \pm 5
Pleasant^d	LE	75 \pm 3	81 \pm 4	82 \pm 3	82 \pm 3
	HE	79 \pm 4	87 \pm 4	82 \pm 4	74 \pm 4

a. Overall the *thick* drinks were rated as thicker than the thin drinks consumed in the *thirst-quenching* context ($p = .028$) but not compared to the thin drinks consumed in the *no-information* ($p = .797$) or *filling* contexts ($p = .101$). All of the thin drinks were rated as similarly thick ($p \geq .919$). The beverage context by energy content interaction indicated that the HE beverage was rated as subtly thicker than the LE version in the *thirst-quenching* group ($p = .011$) but thickness ratings for the LE and HE beverages did not differ in any other groups ($p \geq .177$).

b. The *thick* drinks were rated as thicker than the thin drinks consumed in the *thirst-quenching* context ($p = 0.010$) but not compared to the thin drinks consumed in the *no-information* ($p = .233$) or *filling* contexts ($p = .841$). All of the thin drinks were rated as similarly thick ($p \geq .426$). Overall, there was a main effect of energy content indicating that the LE beverages ($M = 68 \pm 2$) were rated as creamier than the HE beverages ($M = 63 \pm 2$; $p = .023$).

c. Ratings of sweetness and familiarity did not differ across beverage contexts or energy contents.

d. The beverage context by energy content interaction indicated that in the *thick/no-information* group the HE beverage were rated as less pleasant than the LE version. Pleasantness ratings for the LE and HE beverages did not differ in any other groups ($p \geq .238$), although there was a trend for the LE beverages to be rated as slightly less pleasant than the HE versions ($p \geq .065$) in the *thin/thirst-quenching*.

6.4.5 Debriefing questionnaire

No participant correctly identified the purpose of the study to be investigating the role of beverage context on satiety responses to a covert manipulation of a beverage's energy content. Participants' beliefs about the purpose of the study depended on whether they were given extra information about the beverage. In line with the general study cover story, the majority of participants who did not receive explicit information about the drink products (both no-information groups) reported that the purpose of the study was to investigate "food and mood" (61%) with the remaining participants making general suggestions such as "food and appetite" "snacking" and "food behaviour". The majority of participants who received information that the drink was designed to be either thirst-quenching or filling reported the effect of the drink on "mood", "fullness" and/or "thirst" as the purpose of the study (69 %), in line with what they were told, with the remaining participants reporting other things such as "product testing", "overeating" and "food planning". Crucially, no one identified that the drinks differed in energy content. Overall, 69% of participants believed that the drinks they consumed were the same on both days, 11% reported that they "didn't know" whether the drinks were different and 19% identified that the drinks were different because one drink had a different "taste" or one was more "enjoyable" than another. Two of these participants believed that one drink was more filling than the other but did not suggest why.

Table 6.4 The reported expectations of the test drinks, recorded during the debrief session.

	Thin No information	Thin Thirst-quenching	Thin Filling	Thick No information
Thirst-quenching	2	10	0	2
Filling	8	1	9	10
Both	6	6	10	6
Neither	3	0	0	1
Other	0	0	0	0
<i>n</i> =	19	17	19	19

Table 6.4 outlines participants' expectations about the drinks. Most participants in the no-information groups reported that they expected the drinks to be filling. Most participants who were told the drinks would be thirst-quenching reported expecting them to be “thirst-quenching”, while participants who consumed the beverage as a filling snack expected the drinks to be ‘filling’ and “both thirst-quenching and filling”.

6.5 Discussion

The findings from this study indicate that the cognitive and sensory context in which a beverage is consumed can influence the satiety value it affords the consumer.

Participants who consumed thin beverages without any extra contextual information showed a weak satiety response to the additional 197 kcal in the higher-energy test drink, eating the same amount of lunch after both the lower- and higher-energy versions of the beverage. A similar effect was seen in participants who were led to believe that the drinks were designed to be thirst-quenching. However, when the same beverages were presented as a filling snack, participants responded to the additional energy in the higher-energy beverage by adjusting their intake at a later lunch. This effect was also seen in participants who consumed the subtly thicker beverages, who showed the largest adjustment to lunch intake after consuming the higher- and lower-energy beverages. This indicates that for a beverage containing a substantial amount of energy, encouraging people to consider it a snack that will affect hunger and fullness, rather than just a drink, could influence its satiating power. This offers an alternative strategy to modifying a beverage's sensory profile, which is likely to be unacceptable to consumers of many popular low-viscosity but higher-energy beverages such as flavoured waters, soft drinks, sports beverages and energy drinks.

The idea that the context of consumption affects the satiating power of nutrients is consistent with the view that early pre-consumption signals (sensory experience, environmental cues, beliefs and memories about the consequences of consuming a food or drink) integrate with later post-ingestive and post-absorptive feedback from nutrients to determine satiety (Blundell *et al.*, 2010; Blundell *et al.*, 1987). When a food is believed to be satiating these thoughts about the consequences of consuming a product can affect the physiological response to food, such as eliciting slower gastro-intestinal transit time and a larger decline in levels of the orexigenic hormone ghrelin post-ingestion (Cassady *et al.*, 2012; Crum *et al.*, 2011). The early cognitive and sensory signals generated by food and drinks are thought to enhance satiety by priming the appetite system for the delivery of nutrients (Brunstrom, 2007; Davidson & Swithers, 2004). For many low-viscosity energy-containing beverages that are consumed fast and as a drink, the cognitive and sensory cues may not be strong enough to elicit such preparatory responses. Subtle thick and creamy sensory cues can increase the

expectation that a beverage will be more satiating than the same beverage without these cues (McCrickerd *et al.*, 2012), and these sensory modifications (which did not add any energy to the beverages) can also improve the actual satiating power of a higher-energy beverage when it was consumed (Chambers *et al.*, 2013; Yeomans & Chambers, 2011; Yeomans *et al.*, 2014). The current study extends this to show that making the context of consuming an energy-containing beverage more satiety-relevant by changing consumer beliefs alone may also influence its satiety value, but to a lesser extent.

However, in this study early cognitive and sensory cues did not have a general effect on satiety (there was no overall effect of beverage context on lunch intake). This suggests that the satiety-relevant cues did not consistently enhance the satiety value of both the higher- and lower-energy beverages. A potential consequence of an appetite system primed for nutrients is that if the post-ingestive nutrient effects were less than anticipated, a person might actually experience less satiety than if the satiety-relevant cues were absent in the first place. Yeomans and Chambers (Yeomans & Chambers, 2011) reported some preliminary evidence for this effect, which they termed ‘rebound hunger’. They found that making a higher-energy beverage thicker and creamier resulted in reduced intake at a subsequent lunch, however when the same sensory manipulations were applied to a lower-energy version of the beverage participants reported increased hunger and tended to eat more at lunch compared to when they had consumed the same lower-energy drink without these sensory enhancements. Thus, the differences in lunch intake reported in this study could have been due to a decrease in intake after the higher-energy beverage (enhanced satiety), an increase in intake after the lower-energy beverage (rebound hunger), or a combination of both. The participants consuming the beverages in the thick and filling context groups demonstrated the largest response to the beverages energy content, but they also tended to eat the most after the lower-energy beverages. This suggests satiety may have been reduced after the lower-energy beverage when it was presented in a satiety-relevant context, although the appetite ratings do not supported this. Directly testing the combination of satiety-relevant cues and energy levels in foods and beverages that combine to enhance satiety or induce rebound hunger will be an important consideration for future research.

Although explicit beliefs about the consequences of consuming a food can impact the actual satiety value of a food or drink, in the present study changing the sensory rather than cognitive context of beverage consumption had the greatest impact on satiety responses to the additional energy, perhaps because food texture is a strong predictive cue for the presence of nutrients (Davidson & Swithers, 2004), whereas received information (particularly in a laboratory context) may be a less reliable source of information. An alternative explanation for the satiating effect of the thicker higher-energy beverage in this study is that the thickening agent, tara gum, had a post-ingestive effect on satiety. While there is evidence to suggest that consuming similar polysaccharide thickeners (such as guar gum) can reduce appetite, this effect is small and requires much larger quantities of fibre (e.g. $\approx 10\text{g}$ (Wanders *et al.*, 2011)) per serving than the 1.0 g serving used in the present study. Furthermore, the addition of 1.2 g of tara gum to the low-energy thick beverage did not enhance its satiating power in this study nor in our previous research (Chambers *et al.*, 2013; Yeomans & Chambers, 2011; Yeomans *et al.*, 2014), an effect you would expect to see if the tara gum was having an independent effect on satiety. One possibility is that the thickener interacted with the additional energy in the higher energy beverage, perhaps by slowing the digestion of these extra nutrients, but this is unlikely given the small quantity of tara gum used and its subtle effect on viscosity. In the present study consuming higher- and lower-energy beverages in the context of a filling snack also influenced their satiating power, whereas the same drinks consumed with either no information or the belief that it would be thirst-quenching did not elicit different effects on satiety, despite having the same energy difference and the same viscosity as those consumed as a filling snack. Thus, it is plausible that the thicker beverages influenced the satiating power of the additional nutrients through changing their anticipated satiety value rather than an independent post-ingestive effect of the thickener alone.

Despite intake at lunch after the higher- and lower-energy beverages depending on the beverage context, ratings of hunger and fullness did not. Participants reported feeling more full and less hungry after consuming the higher-energy compared to the lower-energy version, indicating that the rating scale used to make these judgements was sensitive to appetite changes. Research suggests that ratings of appetite alone are not always accurate predictors of energy intake at a next meal due to their subjective nature and variation in the way they are expressed by different individuals (Mattes, 1990,

2010; Stubbs *et al.*, 2000). This may help to explain why differences in ratings of appetite were only apparent for the within-participant manipulation of the drink's energy content. Perceived thirst was not affected by any of the beverage characteristics (cognitive or sensory context, or energy content). This is not necessarily surprising because ratings of thirst and motivations to drink are thought to be relatively high and consistent throughout the day (Mattes, 2010; McKiernan, Houchins, & Mattes, 2008), and participants did consume similar amounts of water across the test days.

A limitation of the study is that we did not formally assess what participants' expected from the beverages as they were consuming them, relying instead on debrief reports once the study was complete. As this study was conducted in a laboratory it was anticipated that demand effects would heavily influence a measure of expectations taken at the point of consumption, particularly for participants who received explicit information about the beverages. This could have affected later lunch intake if participants felt that they had to eat in accordance with their rated expectations. However, measuring expectations retrospectively as we did may have provided a less accurate report of each participant's true expectations. Nevertheless, the debrief data did suggest that the participants expected the drinks to be more filling and thirst-quenching in accordance with the information they received, and as the main findings of the study were in line with the prediction (that participants would be better able to respond to the energy content of the beverage when they were consumed in a context more consistent with satiety) this indicates that the cognitive manipulations were successful for the most part.

It was unexpected that the sensory evaluations of the test drinks would be influenced by our cognitive manipulations. The thicker beverages were rated thicker and creamier than the thin versions only when consumed in the thirst-quenching context, even though participants in the other two beverage context groups (*filling snack* and *no-information*) consumed the same thin beverages. In our previous research these subtle textural manipulations were highly perceptible when thick and thin versions were compared side-by-side in a taste test and the higher- and lower-energy versions were well matched (McCrickerd *et al.*, 2012). In the present study participants consumed either thin or thick versions of the beverages, so differences in perceived thickness and creaminess were probably less evident between beverage context groups as they were when

compared by the same person. Importantly, the higher- and lower-energy beverages were fairly well matched for sensory characteristics and participants were not aware of the energy manipulation within the test-drinks.

Overall, data from this study indicates that changing certain features of energy-containing beverages can influence the effect it has on the amount of food subsequently consumed: changing the context in which a beverage is consumed from a *drink* to a *snack* impacts a person's satiety response to the energy it contains, although the most effective strategy was to change its sensory characteristics to be more predictive of nutrients. These data represent short-term influences on eating behaviour within a laboratory environment where food intake was controlled. To move forward, it is important to consider whether consuming energy-containing beverages in a more satiety-relevant context will influence satiety responses outside of a laboratory setting, when a person not only decides how much of a food they consume but also what and when they eat or drink. Encouragingly, contextual cues from a products marketing, labelling, presentation and sensory profile can influence eating behaviour in real-world settings such as in restaurants, supermarkets and at home (Cohen & Babey, 2012). Energy rich meal-replacement beverages can have a positive impact on intake regulation and even promote weight loss when consumed in the context of "food" (Heymsfield *et al.*, 2003), albeit in people committed to losing weight. Future research should focus on appropriate ways to promote liquid calories as fuel rather than fluid and to determine the impact of this approach over the longer term on product selection and energy intake.

6.5.1 Author Contributions

KMc designed the study with input from LC and MRY. KMc prepared the study materials, collected and analysed the data, including the viscometry, and drafted the manuscript with commentary from LC and MRY. All authors read and approved the final manuscript. The authors declare that they have no competing interests.

7 General discussion

7.1 Conclusions

The overview presented at the beginning of this thesis outlined the evidence suggesting that the regular consumption of caloric beverages is linked to weight gain. A wealth of research now suggests that caloric beverages might contribute to weight gain because they have a weak satiating effect compared to the same energy load consumed in other food forms, perhaps because liquids are more rapidly processed throughout the gastrointestinal tract, but also because early cognitive and sensory cues present at the time of consuming a low-viscosity caloric beverage are not predictive of their energetic value. Indeed, the development of satiety is a product of more than the physiological response to nutrient delivery; the sensory experience during consumption and our prior perceptions and beliefs can all moderate the satiating power of foods and drinks.

The papers presented in this thesis investigated the possibility that early cognitive and sensory cues can be manipulated to generate beliefs and expectations about the potential satiating effect of a caloric beverage, and then tested in various ways as to how these expectations might impact actual eating behaviour and the experience of satiety post-consumption. The following sections (7.1.1 to 7.1.3) summarise the main conclusions reported in papers one to five, with a focus on the three questions outlined in the overview (1.4):

- 1.** Are beverages expected to be less satiating than other food forms?
- 2.** Are the sensory characteristics of caloric beverages limiting their anticipated satiating power, and can they be enhanced to increase expectations of satiety and influence behaviour?
- 3.** Can satiety-relevant cognitive and sensory cues influence the satiating effect of nutrients consumed as a beverage?

7.1.1 Are beverages expected to be less satiating than other food forms?

Paper one explored the idea that the expected impact a food or beverage will have on hunger, fullness and thirst is based in part on the product's sensory and nutrient characteristics. Overall, the beverage products tested were expected to be relatively

satiating and similar to other non-beverage products of similar energy content. This was initially surprising since it has been suggested that caloric beverages might have a weak impact on satiety if they are not expected to be satiating (Mattes, 2005, 2006a). However, the food and beverage products used in this study varied largely in energy content, serving size and labelled information, therefore the question still remains whether on a calorie for calorie basis beverages are considered as less satiating than other food forms. Beverages tended to be served in larger portion size, primarily owing to their large water content, and this may have contributed to their expected satiating effect. Yet, in this study the product's serving size was not significantly related to its expected satiating effect, i.e. the products served in the larger portions were not necessarily the ones expected to be most satiating. Instead, the extent to which a food or beverage was expected to be filling and to suppress hunger was best predicted by its actual nutrient content; products that had a higher energy content were expected to be more satiating. Evaluating the expected satiating effect of food and beverage products in the qualities they would be purchased, and then consumed, is arguably more realistic of real-world consumer experience. However, more controlled research will be required to clarify the role of serving size in expectation of satiation and satiety.

There was evidence that perceived creaminess was an important sensory cue related to the presence of energy in the products tested in this paper. More generally these data indicate that people have a good idea of the energy content of a range of foods and beverages, relative to each other, and this knowledge in part informs satiety expectations. It is likely that front-of-pack product labels and branding visible in the food images we used, such as “sugar free”, “low-calorie” and “diet”, contributed to these expectations.

Whilst caloric beverages presented in their usual serving size were not necessarily expected to be less satiating than other food products of similar energy content, there was clear evidence that beverages were expected to be the most thirst-quenching products overall, as predicted. This was independent of the beverages' energy content. Instead, the products' expected impact on thirst was best predicted by their anticipated salty taste and thicker/harder textural characteristics. This suggests that a beverage's association with thirst-reduction might promote calorie consumption if caloric

beverages are consistently chosen over, for example, water or low-calorie diet drinks (promoting passive overconsumption).

7.1.2 Are the sensory characteristics of caloric beverages limiting their anticipated satiating power, and can they be enhanced to increase expectations of satiety and impact behaviour?

The findings from paper one suggest that beverages anticipated to be not as creamy and to have a thin texture would be expected to be thirst-quenching but not necessarily as satiating as other foods or beverages that are anticipated to be thicker and creamier. With this in mind, adding satiety-relevant sensory characteristics to a beverage may increase the extent to which it is expected to be satiating. Paper two (McCrickerd *et al.*, 2012) sought to determine whether small manipulations of the thick and creamy characteristics of a model test beverage influenced the extent to which it was expected to be satiating. Findings from experiment one indicated that across a range of 16 beverage samples, untrained participants were able to detect subtle differences in beverage viscosity, and that small increases in viscosity (without influencing energy content) led to a beverage being perceived as thicker and creamier, but similarly pleasant. In experiment two a different group of untrained participants evaluated the potential satiating effect of beverages designed to overtly differ in thick texture and creamy taste, and covertly differ in actual energy content. Eight beverages were created consisting of two energy levels (higher-energy and lower-energy) and four sensory contexts (thin/low-creamy; thin/high-creamy; thick/low-creamy; thick/high-creamy). Findings indicated that beverages differed in the extent to which they were expected to be satiating, depending on their sensory characteristics. Moreover, satiety-relevant textural rather than taste cues had the biggest impact on these expectations: participants consistently expected the subtly thicker versions of the beverages to be more filling and to have a greater suppressant effect on hunger, regardless of actual energy content, whereas the creamy flavour manipulation had little impact on these expectations.

Paper three (McCrickerd, Chambers, & Yeomans, 2014a) investigated the potential for satiety-relevant expectations to influence decisions about consumption, by serving participants four versions of the same iso-energetic beverage with and without thick and creamy texture and taste additions (using the same four sensory contexts as those created in paper two). Participants could consume as much as they liked of the

beverages and it was hypothesised that they would select and consume less of the beverage that was expected to be the most satiating, which (based on the findings from paper two) was anticipated to be the thicker versions of the beverages. The results confirmed that this was true for female participants, who selected and consumed approximately 20% less of the subtly thicker test beverages, and in line with the findings from Paper two the addition of creamy flavours did not affect intake. The vast majority of the participants consumed everything they served themselves each day, suggesting that differences in beverage intake consumed in the different sensory contexts reflected the decision to select a smaller portion size. Interestingly, male participants did not adjust their intake in response to the beverage's sensory cues. As discussed in the paper this was possibly because the male participants were using portion cues generated by the size of the glass to guide intake. Finishing a serving is an important external cue for meal termination, which may have been particularly salient to the male participants because their average portion selections tended to be the same or more than the capacity of the glass they had to consume from. This, however, was not true of the females who on average consumed approximately 100g less than the glasses capacity, and so were likely to have encountered this cue less. Decanting a portion of a beverage from a larger container is arguably a good reflection of real consumer behaviour, and these data demonstrate the subtlety with which satiety expectations generated by sensory cues are likely to influence real life eating behaviour.

The finding that creamy flavour additions did not strongly enhance the anticipated satiating effect of the beverages (paper two), or self-selected consumption (paper three), was in contrast to the finding that anticipated creaminess was the sensory cue most strongly associated with expectations of satiation and satiety (paper one). However, perceived creaminess is a multi-modal sensory property with both textural (thickness and smoothness) and taste (dairy, vanilla and sweetness) characteristics, and, whilst the addition of creamy *flavourings* to the beverages had little impact on expectations and behaviour (papers two and three), *perceived* creaminess generated by the increased viscosity of the thicker beverages was really important: the thicker beverages were consistently rated as thicker *and* creamier. Both sweet taste and texture are important associative cues for energy and these relationships are thought to be some of the earliest associations between a taste and nutrients formed in humans and other animals (Blank & Mattes, 1990; Davidson & Swithers, 2004; Sclafani, 1997). It is likely, however, that

over a lifetime of consuming different foods and beverages, texture cues (which incorporate thickness and creaminess) become particularly satiety-relevant in a beverage context because they increase oro-sensory exposure time (see 1.3.2.2), and reliably signal the presence of nutrients in a food, more so than taste cues alone (see 1.3.2.3 and 1.3.2.4).

In summary, satiety-relevant sensory cues can be added to a caloric beverage to enhance the expectation that it will be satiating. Expectations generated by the sensory characteristics can guide portion size decisions, but these effects on real-world eating behaviour are likely to be subtle in the face of other portion size cues.

7.1.3. Can satiety-relevant cognitive and sensory cues influence the satiating effect of nutrients consumed as a beverage?

The findings from paper two indicated that when people were unaware of a beverage's actual energy content, those perceived to be thicker and creamier would be expected to be more filling and to suppress hunger more than the same beverage without these cues. Papers four and five investigated the possibility that these expectations would have different effects on the development of satiety depending on the actual energy content that is delivered post-consumption, and that beliefs generated by labels and contextual cues could influence this further.

Using food-diary methodology, paper four measured the expected and actual satiating power of higher- (HE) and lower-energy (LE) beverages consumed at a fixed time with different combinations of labelled satiety messages and thicker/creamier sensory cues. Food intake and eating patterns were recorded for each participant on each day a beverage was consumed. However, due to an insufficient sample size, it was hard to draw firm conclusions from the data presented in paper four. Despite this, results provided tentative evidence that a high-satiety beverage label enhanced the expectation that the beverage would be filling, particularly when combined with thick and creamy sensory characteristics. Moreover, there was some suggestion that this combination of enhanced cognitive and sensory cues led to improved energy-intake regulation after consuming a higher-energy beverage: participants tended to compensate completely for the additional 201 kcal consumed in the HE beverage (by consuming slightly less over the course of the test day) when they consumed the LE and HE beverages in a thick and

creamy context with congruent labelling (LE labelled “Lighten” and the HE labelled “Stayfull”). This was less evident when participants consumed the thicker HE beverages with incongruent or no labelling, and participants showed very little compensation when the beverages did not have the enhanced sensory cues, regardless of the labelled satiety messages. These findings should be interpreted with caution as the study was under powered. However, the study does highlight the potential ways in which the cognitive, sensory and nutrient characteristics of a caloric beverage might be combined to optimise their anticipated and actual satiating power.

Adding satiety-relevant cognitive and sensory cues to beverages might draw a person’s attention away from expectations of thirst-reduction and towards their potential satiating effect, which in turn might influence the development of satiety post-consumption. This was further explored in paper five (McCrickerd *et al.*, 2014b), which demonstrated that consuming low-viscosity beverages without any extra contextual information led to a weak satiety response to the additional 197 kcal in the higher-energy test drink: participants ate a similar sized lunch after both LE and HE versions of that beverage. Importantly, the satiating effect of the beverage was not significantly enhanced by presenting the beverage in the context of a “thirst-quenching drink”, suggesting that consuming caloric beverages in the context of thirst can lead to energy intake that is not compensated for in a later meal (although there was a trend for a better compensatory response to energy than when the same product was consumed without any expectation manipulation). On the other hand, when the same low-viscosity LE and HE beverages were consumed as a “filling snack”, participants significantly responded to the energy difference by adjusting their intake at a later lunch. This indicates that encouraging people to consider a higher-calorie beverage as a snack could impact the satiating power of its nutrients. However, the largest impact on satiety responses was seen in the group of participants consuming the beverages in the thicker sensory context without any additional information (included as a positive control in paper five, and replicating previous work in this laboratory: Chambers *et al.*, 2013; Yeomans & Chambers, 2011; Yeomans *et al.*, 2014). These participants demonstrated the largest adjustment to energy intake at the later lunchtime meal.

The finding that the satiety-relevant sensory manipulation had a larger impact on satiety responses to the nutrient loads than manipulating beliefs alone, indicates that cognitive

and sensory cues can influence the satiating power of a beverage, but that their contributions may not be equal and potentially operate via different mechanisms.

7.2 Implications

This thesis set out to investigate realistic ways to improve the satiating effect of nutrients consumed in a beverage, and findings clearly demonstrated that people can easily over-consume an additional 200 kcal in their daily diet if consumed as a low-viscosity beverage. If every day a person consumed 200kcal from a low-viscosity caloric beverage with a weak impact on appetite and energy intake control, in an extreme case this could add up to an extra 73,000 kcal consumed over the course of a year, which could have real implications for weight gain if stored as body fat. Thus, one of the first implications of this work is to inform the design of beverage products with a more effective impact on satiety. Food companies interested in developing new *satiating* beverages could firstly consider whether the product's sensory profile is predictive of its energy content: adding soluble fibres such as tara gum to beverages will help achieve this by modifying their sensory characteristics to be thicker and creamier and more in line with their caloric content. These products could be marketed as 'foods' rather than beverages, to help consumers recognise the energy they contain. Food retailers might also consider changing the context within which many caloric beverages are currently sold in their establishments. In the UK caloric beverages are often sold as part of a "meal deal" where customers select a *drink* to go alongside their *food* items, and while this context emphasises the thirst-quenching ability of beverages it fails to acknowledge their potential energetic value: in the supermarket chain Sainsbury's, one of the 'drinks' included as part of their meal deal contains 280 kcal. Promoting water or low-calorie beverages as the best drink option and caloric beverages as a snack would make the context of consumption more relevant to the energy being consumed.

The finding that subtle differences in the sensory characteristics of a food or beverage can influence the extent to which they are expected and experienced as satiating has real methodological implications for research investigating satiety and energy intake regulation. Test-foods need to be matched for characteristics such as thickness and creaminess and/or acknowledge these differences as a potential confounding factor.

This is particularly relevant to test foods differing in energy content, which might be detected sensorially. Where possible, and particularly for liquids, the oro-sensory profile of foods should be fully evaluated to characterise the potential impact of these sensory differences on eating behaviour. This might include some or all of the following: physiochemical measures of the food, such as rheology and tribology; evaluation of perceived sensory characteristics; microstructure of eating behaviour, such as eating rate and effort; expected impact on hunger, fullness and thirst. It is notable that many studies that have used similar preload designs make claims for nutrient effects (such as the satiating power of both polydextrose and whey protein added to a beverages in quantities of up to 25g) that could have been influenced by differences in sensory characteristics, but were either not measured and reported (Hull, Re, Tiihonen, Viscione, & Wickham, 2012; Zafar, Waslien, AlRaefaei, Alrashidi, & AlMahmoud, 2013) or not acknowledged as a contributing factor (Astbury, Stevenson, Morris, Taylor, & Macdonald, 2010; also see section 1.3.2.1 on food form; Astbury, Taylor, & MacDonald, 2013).

Finally, while cognitive and sensory influences on the development of satiety have been recognised (1.3.2), what is rarely considered in this literature is how these influences interact, both with each other and with the actual energy content of a food or beverage to influence satiety. The evidence presented in this thesis (particularly in paper five) demonstrates that early cognitive and sensory cues might have a different impact on the development on satiety depending on the actual energy content that is delivered post-consumption. Thus, research investigating early influences on satiety must consider whether such effects are general (influencing satiety no matter the food eaten and energy content) or dependent on other characteristics of the food item, such as the energy load delivered.

7.3 Wider discussion points

Study-specific conclusions are discussed in depth in each paper, however, there are several wider points worth considering further, including possible mechanisms for enhanced satiety, limitations and future directions.

7.3.1 Possible mechanisms

Based on the research outlined in the overview and papers, it is anticipated that early cognitive and sensory cues generated by a food, influence the cascade of psychological and physiological signals for ingestion, which act to prepare the body for the optimal digestion and absorption of nutrients and improve the efficiency of energy intake regulation (section 1.2.1.1). Physiological responses to the sight, smell and oro-sensory experience of food include salivation, gastric and intestinal secretions, and release of early gastrointestinal hormones, such as pancreatic polypeptide, CCK, GLP-1, insulin and ghrelin release. These early cephalic phase responses are thought to *combine* with later post-ingestive nutrient effects (section 1.2.1.2 and 1.2.1.3) promoting gastrointestinal hormone release, speed of gastrointestinal motility and nutrient oxidation, to determine the experience of satiety. The evidence presented in this thesis is in line with this explanation, indicating that nutrients consumed as a beverage had the largest impact on satiety when the energy content was cued with satiety-relevant beliefs, expectations or sensory cues. In this way, these cues were not acting as placebos, altering satiety by themselves; instead they moderated the impact of the ingested nutrients on satiety.

Paper five demonstrated that altering explicit expectations about the satiating effect of a beverage, without altering the beverage itself, significantly influences satiety responses to the nutrients. This demonstrates that cognitive processes alone have an impact on subsequent processing of ingested nutrients, but that the sensory manipulation had a larger effect. A likely explanation for this finding is that the oro-sensory experience of food, in particular texture, is a stronger predictive cue for the presence of nutrients (Davidson & Swithers, 2004). This can be seen in papers one and two, where thick and creamy sensory characteristics helped to guide expectations of satiation and satiety, and are associated with nutrient content of commonly consumed foods: foods expected to be thicker and creamier tended to be higher in energy. Thus a satiety-relevant sensory experience may be a more reliable, and even believable, conditioned cue for nutrients, compared to labelled or contextual information, which can impact both the cognitive (e.g. explicit thoughts and beliefs about the satiating consequences of a food) and physiological (e.g. increased preparatory cephalic-phase responses) anticipation of nutrients.

This thesis, however, focussed on behavioural outcomes by measuring expectations, sensory and hedonic evaluations, and food intake behaviour, and as such provides no direct evidence for potential physiological mechanisms behind the cognitive and sensory influences on satiety. Recent findings by Cassady *et al.* (2012) have begun to shed some light on this, by assessing the contribution of beliefs (that a product will be solid vs. liquid in the stomach) and oro-sensory characteristics (liquid beverage vs. solid jelly) to the development of satiety after consuming equicaloric foods (see 1.3.2.1 for full details). They found that consuming a liquid beverage was associated with faster gastric emptying and gastrointestinal transit times, a smaller decline in ghrelin and reduced insulin and GLP-1 release relative to consuming a solid jelly. On the other hand, beliefs modified gastrointestinal transit times, which were shorter when the product was believed to be liquid in the stomach, and primarily influenced appetite and later intake, with participants consuming less at a test meal 4 hours later and feeling less hungry and more full in this time when they believed the product was solid rather than liquid in their stomach (regardless of the oro-sensory experience). This suggests that the oro-sensory experience of a food or beverage has the biggest impact on physiological satiety responses while cognitions have a greater impact on behaviour, but contradicts evidence from paper five indicating that the sensorially enhanced higher-energy beverage influenced subsequent food intake more than the cognitively enhanced version.

In the study of Cassady *et al.* (2012) the products were designed to offer a similar gastric challenge, which was not the case for the beverages designed in this thesis, which differed subtly in fibre content (tara gum 0 - 1.3 g) and considerably in energy content (≈ 200 kcal difference). It is conceivable that the increased viscosity achieved by adding tara gum to the beverages might have a post-ingestive effect on satiety that was not present in the beverages consumed as a filling snack. However, the finding that the addition of tara gum did not enhance satiety when added to a lower-energy beverage does not support this explanation, suggesting instead that the addition of the tara gum thickener *interacted* with the beverage's energy content to influence satiety. Some evidence does suggest that this is possible: French and Read (1994) asked participants to consume a high-fat (248 kcal) and low-fat (30 kcal) soup, both with and without 12g of guar gum (a similar non-ionic galactomannan polysaccharide thickener to tara gum, although at a much higher concentration than the subtle use of thickeners in the studies

in this thesis). The researchers found that the addition of guar gum to a low-fat soup delayed the return of appetite compared to the low-fat soups without the guar gum. However, this effect was far more pronounced when participants consumed the high-fat soups with and without the guar gum, showing an interaction between the guar gum concentration and the soup's energy content on appetite regulation. The researchers attributed the general ability of guar gum to suppress appetite on the delayed gastric emptying of the more viscous soup, but the particularly powerful satiating effect of the more viscous high-fat soup was ascribed to the prolonged transit time of the soup in the small intestine, slowing the rate of absorption.

Given the low levels of tara gum used in this thesis (maximum 1.3 g ingested compared to the 12g of guar gum used by French and Read, 1994) it is unclear whether the subtle differences in viscosity achieved by this thickener could have a similar impact on gastrointestinal transit time and whether this could account for the enhanced satiating effect of the thicker HE beverage. Thus, without the appropriate physiological measurements, it is difficult to discern the exact mechanism (or combinations of mechanisms) by which the satiety-relevant sensory and cognitive manipulations influenced the satiating power of the beverages.

On the other hand, only considering gastrointestinal influences may overlook other key factors that could account for the *behavioural* satiety responses reported in this thesis. For example, memory for foods can influence eating behaviour and a stronger for recent eating has been shown to reduce future energy intake (Higgs & Donohoe, 2011; Higgs & Jones, 2013; Higgs *et al.*, 2008). In particular, attending to the sensory characteristics of a food increased both memory for eating that food and the extent to which it suppressed hunger and reduced later snacking (Higgs & Donohoe, 2011). Researchers have suggested that a greater memory for recent eating might influence later food intake by increasing attention to and interpretation of internal cues for satiation and satiety in the time between eating occasions (Hetherington *et al.*, 2006; Higgs & Donohoe, 2011; Mitchell & Brunstrom, 2005; Ogden *et al.*, 2013). It is possible that a low-viscosity beverage is consumed too fast for a person to strongly attend to the sensory experience and form a lasting memory of consumption, potentially limiting the beverage's satiating effect post-consumption. This might be improved if attention is directed to the potential satiating effect of a caloric beverage, by amplifying the cognitive and sensory

experience to be more satiety relevant. For example, presenting the beverages as in a ‘filling snack’ or with thicker sensory cues, as we did in paper five, may have provided a satiety-relevant context for participants to interpret the beverage’s post-ingestive effect. However, one might expect that attending to internal cues for satiety would impact a person’s reported experience of hunger and fullness, yet there was very little evidence across the papers to suggest that different beverages impacted rated appetite. Thus, the potential role for attention and memory on the satiating effects of energy consumed as a beverage cannot be ruled out, but requires proper investigation.

7.3.2 Thirst

While the enhancement of expected and actual satiety generated by caloric beverages was the main aim of this thesis, the beverages had the ability to be thirst-quenching as well as satiating and consequently it was important to measure their impact on thirst alongside other appetite sensations. There was no clear evidence that perceived thirst was either affected by the beverages’ characteristics (papers two, three, four or five), or associated with changes in intake of food (papers four and five) and water (paper five). Thus, it is unlikely that thirst could have accounted for the main findings in this thesis. However, paper one demonstrated that beverages are uniquely associated with thirst-reduction, regardless of their nutrient value, suggesting that anything that augments thirst, such as exercise and sweating or consumption of salty foods, could promote the consumption of energy in beverage form. Thirst and drinking are tightly controlled by a physiological system that initiates both intake and conservation of water and sodium levels in the body, in order to maintain blood plasma volume and osmotic pressure at healthy levels (Thornton, 2010). Participants were in no way water deprived in any of the research present in this thesis, thus it is unsurprising that thirst was generally unaffected by the beverage manipulations.

7.3.3 Limitations

7.3.3.1 Methodological considerations

A major methodological consideration is the laboratory setting in which the majority of this research was conducted. Due to the multifaceted nature of energy intake regulation, utilising controlled laboratory studies to isolate and measure the cognitive, sensory and nutrient influences on the satiating power of a beverage was deemed necessary.

However, this required participants to periodically fast both before and after certain test

sessions (papers one, two, three, four and five), evaluate foods before consumption (papers two, three, four and five), evaluate their appetite across set time points (papers one, two, three, four and five) and consume foods in both fixed and *ad libitum* portions at specific pre-defined times of the day (papers three, four and five). All of these measures increased the sensitivity of the research to detect differences in eating behaviours that could be attributed to the beverages, but in doing so compromised the naturalness of the participants' experience and may also have missed later adjustments to intake occurring outside of the laboratory (specifically papers, three and five). Ultimately, as with all laboratory based research, it is unclear whether these findings would translate into real-world eating behaviours. It should be noted that paper four employed food diary methodology in an attempt to measure the impact of beverages enhanced for satiety on eating behaviour outside of the laboratory. What was clear from this study, however, was that completing the food diary even for a day proved effortful and unnatural for many participants, who reported that using the diary did affect what they consumed. Thus, more naturalistic methods also have their flaws, so a combination of both laboratory and naturalistic studies is likely to provide the most rounded measure of factors affecting the development of satiety (Blundell *et al.*, 2010; de Castro, 2010).

A related methodological factor limiting the extrapolation of these findings is the measurement of lunch intake in paper five, which was conducted using a single-item meal, pasta and tomato sauce. It could be argued that this homogenous food was an unrealistic meal option because people often consume multi-item meals and pasta and sauce might be more appropriate for an evening meal, rather than lunch. An alternative approach would have been to offer a multiple course meal or a buffet-style lunch, where participants can select what to consume from a range of items. However, paper five was interested in short term energy intake and compensation for additional nutrients in the beverage 'preload', and an important feature of a test meal is for it to be sensitive to the experimental preload manipulations (Blundell *et al.*, 2010). While the variety offered by multi-item buffet is good for measuring aspects of intake such as food choice and/or preferences for different macronutrients or energy density, this was not the aim of that study. Instead, meal variety can promote intake (Norton, Anderson, & Hetherington, 2006) and this might further depend on the participants' preferences and selection of the foods, therefore a single meal of pasta and sauce was deemed more

appropriate. Furthermore, when asked in the debrief questionnaire whether the pasta lunch was something they would normally consume for their lunch specifically, most participants reported they would eat this meal “sometimes” and “often” (62% and 28% respectively) whilst few reported “never” (9%).

Another potential limiting factor of this research was the decision to not use trained sensory panellists to evaluate the test foods. Participants were asked to make the sensory and hedonic ratings by taking a sip and “moving it around in their mouth while they count to three” before swallowing. They then evaluated the beverages for characteristics such as thickness, creaminess and fruitiness, and with the exception of study one in paper one participants received no direction as to what these sensory characteristics meant. Thus, these evaluations were open to each individual’s interpretation, which probably contributed to the inconsistency in ratings across studies. Namely, the thick and creamy sensory manipulations were clearly rated as thicker and creamier than the beverages without the sensory enhancements in paper two, but less consistently measured across a longer time period (paper three) and between different groups of people (paper four and five). Variation was particularly noticeable for the creamy ratings, since perceived creaminess is multimodal (Chen & Eaton, 2012), depending on a range of taste and texture attributes that people may interpret differently. However, it was deemed that leaving participants un-trained would increase the likelihood that the sensory evaluations (and the satiety-relevant expectations they might generate) would be more representative of the sorts of evaluations real consumers would make and potentially use to guide food intake outside of the laboratory.

7.3.3.2 Alcohol and caffeine

It is important to re-emphasise that these findings cannot be extended to caffeinated or alcoholic beverages, which were not considered in any of the papers presented in this thesis, or the vast majority of research discussed (see start of section 1.2). However, how regular consumption of these beverages might influence energy intake regulation will be important to consider in future research.

Alcohol is caloric (1 g alcohol contains 7.1 kcal), and like many caloric beverages, alcoholic beverages appear to have a weak impact on short term intake regulation, and alcohol (independent of the beverages main macronutrients) has even been shown to

promote an increase in food intake in some, but not all, investigations (for recent reviews see: Kokavec, 2008; Yeomans, 2010a). The obvious implication of this is that alcohol consumption could contribute to weight gain, which would make enhancing the satiating power of alcoholic beverages a key focus of future research. Paradoxically, the link between regular alcohol consumption and increased body weight remains unclear, with some researchers reporting positive associations (Chakraborty, 2014; Lukasiewicz *et al.*, 2005; Schröder *et al.*, 2007; Shelton & Knott, 2014), whilst others have suggested this relationship depends on the type of alcoholic beverage and pattern of consumption (Dumesnil *et al.*, 2013; Lukasiewicz *et al.*, 2005; Sayon-Orea, Martinez-Gonzalez, & Bes-Rastrollo, 2011), and a person's gender (Barry & Petry, 2009; Wannamethee & Shaper, 2003).

On the other hand, caffeinated beverages are the beverage industry's biggest growing group of products, incorporating tea and coffee based products and energy drinks (Kleiman *et al.*, 2012). Many caffeinated beverages contain a substantial amount of calories: for example, the tea and coffee based products available at STARBUCKS® range from 3-695 kcal per beverage, and a can of the caffeinated drink Monster Energy contains 240 kcal (per 500ml can) primarily from carbohydrate. In terms of appetite regulation, ingesting caffeine has been linked to reduced body weight and increased thermogenesis and metabolic rates in humans (Bracco, Ferrarra, Arnaud, Jequier, & Schutz, 1995; Tagliabue *et al.*, 1994) which could account for the evidence linking regular tea and coffee consumption to reduced energy intake and weight gain (Bakuradze *et al.*, 2014; Lopez-Garcia *et al.*, 2006). However, more recently consuming caffeine alone has been shown to have no notable impact on appetite or satiety responses (Greenberg & Geliebter, 2012), but may when in combination with other substances such as fibre and green tea catechins (Carter & Drewnowski, 2012), and nicotine (Jessen, Buemann, Toubro, Skovgaard, & Astrup, 2005). This suggests that aspects of coffee and tea based products, other than caffeine, could be contributing to their proposed link to weight control.

Two features of alcoholic and caffeinated beverages stand out. Firstly, regardless of any acute effects of alcohol or caffeine on appetite, these beverages often contain various other bioactive compounds alongside the main energy source (often carbohydrate), for which the effects on appetite regulation are unclear: for example,

ginseng and taurine are often added to energy drinks and catechin flavanols are present in many wines and teas, which could have an independent influence on eating behaviour (Woon & Toh, 2014). A second noteworthy feature of these products is that they can be consumed in a variety of contexts, not necessarily associated with satiety. For instance, caloric caffeinated energy drinks and sodas are often consumed for alertness and alcohol can be consumed in specific social contexts for its relaxing and/or disinhibiting effects. Given the findings in this thesis, it would be interesting to consider whether these contexts affect the satiating potential of these beverages.

7.3.3.3 Participants

Finally, the research presented in this thesis was conducted on a relatively limited participant population, predominately young, healthy, non-obese and educated University of Sussex students and staff. Papers two and three tested male and female participants while papers one, four and five females only. The decision to test only females was deemed appropriate since males and females did not differ in their expectations of satiety based on the sensory characteristics of the beverages in study two (McCrickerd *et al.*, 2012) and whilst males tend to eat more than females, previous work indicated that they showed similar satiety responses to beverages varying in satiety-relevant sensory characteristics and energy content (Yeomans & Chambers, 2011).

Additionally, to limit the chances of participants actively restricting their food intake at the test meals and throughout the day, papers four and five only recruited low restrained individuals. Paper one reported some preliminary evidence that a participants' tendency to restrict intake (restraint) and to overeat (disinhibition) moderated the expectation that foods and beverages perceived to be creamier would be more satiating. The ability to learn that certain sensory cues predict nutrients has been shown to vary across individuals with different eating styles (Brunstrom & Mitchell, 2007; Shaffer & Tepper, 1994; Tepper, 1992; Yeomans, 2010b). It will be important, therefore, to test whether beverages optimised for satiety using satiety relevant predictive cues have a similar effect on appetite regulation across a variety of individuals. Of particular interest would be those who are overweight and obese and/or identify themselves as dieters, as these may be the consumers most interested in buying a satiating beverage product.

7.4 Future direction

In addition to some of the ideas and implications already mentioned (see 7.2 and 7.3), the findings of this thesis could be extended in a number of ways. The main findings from paper five are promising because they suggest that the satiating power of higher-energy beverages can be influenced by the addition of satiety-relevant sensory characteristics, but also (to a lesser extent) by consuming the beverage in the context of a snack, rather than a drink. Given the tentative suggestion in paper four that satiety-relevant sensory and labelled cues can combine to enhance compensation for nutrients consumed in a beverage, a future study could investigate whether the thicker beverages consumed in paper five would have an even greater impact on satiety responses if they too were consumed in the context of a snack.

Another important consideration will be to assess whether repeated consumption of these beverages (giving participants enough exposure to learn about the their satiating effect) would modify the relationship between preparatory cognitive and sensory influences and the actual nutrient effects. A recent study from our laboratory indicated that sensory-enhanced satiety changes with repeated consumption, with participants becoming more effective at suppressing appetite and later intake after in response to the energy content of a thin and less creamy beverage after six exposures (Yeomans *et al.*, 2014). Another study could investigate whether consuming the thin beverages in the context of a filling snack would enhance a person's ability to learn about the satiating effects of a higher energy low-viscosity beverage. This would test whether manipulating a person's beliefs could have sustained effects on satiety responses and could be an interesting line of enquiry as there is currently no consistent evidence indicating that inherent beliefs about the satiating consequences of a food will be modified with repeated exposure, despite behavioural changes in response to the energy content (Hogenkamp *et al.*, 2012a; Wilkinson & Brunstrom, 2009; Yeomans *et al.*, 2014).

Considering whether satiety-relevant sensory and cognitive cues can have a sustained effect on satiety *outside* of the laboratory setting would be the next step. This could be achieved in a number of ways, using quasi-experimental designs. Firstly, participants could be assigned to one of the beverage groups detailed in the example study protocol

in Figure 7.1, contrasting the contextual information that the beverage is a drink (for thirst) or a snack (for satiety) and the sensory contexts of lower- vs. higher-viscosity sensory contexts. The satiating effect of HE and LE beverages pre- and post-exposure could be evaluated using a laboratory-based preload paradigm such as the one employed in paper five, with participants consuming the beverages at home in the exposure periods between testing. Moreover, food diaries could be added into this design, with participants recording daily food and beverage intake on the satiety testing days, and even throughout the exposure period. Although a less controlled measure of satiety, this methodology could provide insight into the different ways in which the beverages may be incorporated into every day eating behaviour: for example, is a beverage more likely to be consumed alongside a meal if considered a drink rather than a snack? Another potential advantage of a more real-world record of eating behaviour is that the contextual manipulation might be more convincing outside of the laboratory environment. However, based on participant feedback in study four, ways in which the effort of diary recording could be improved whilst still promoting compliance and accuracy, would need to be considered.

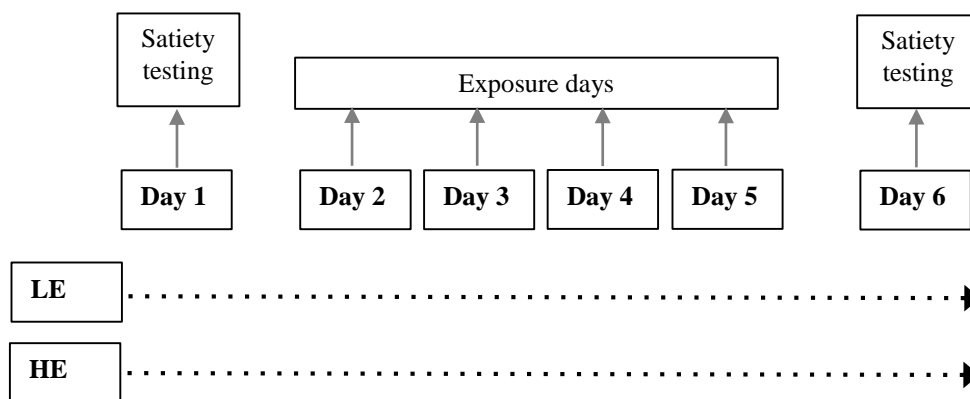


Figure 7.1 Schematic summary of an example study protocol for testing whether the satiating effect of a beverage enhanced for satiety is sustained with exposure in a real-life setting. These beverages could be consumed in one of four beverage contexts: thin “drink” vs. thin “snack” vs. thick “drink” vs. thick “snack”. This example has four exposure days, but more or less could be considered.

Another line of enquiry could consider the minimum amount of energy needed to be combined with satiety-relevant cues to achieve enhanced satiety (decrease in appetite

and future intake) and avoid rebound hunger (an increase in appetite and intake). A recent study reported that labelling a lower-energy yogurt (180 kcal) as high calorie, led to reduced appetite and intake at a later meal compared to a low calorie label, but a similar effect was not seen a higher energy yogurt (530 kcal) (Hogenkamp *et al.*, 2013). Perhaps preparatory responses to nutrients, generated by beliefs, expectations and early sensory cues, only impact satiety if the energy content delivered is high enough to elicit sufficient post-ingestive feedback, but low enough for early influences to be relevant for efficient satiety. Based on the beverages developed as part of this thesis, several versions could be designed to range in caloric context between 0-200 kcal. These could be consumed in cognitive and sensory contexts of interest (some examples and a suggested protocol is presented in Figure 7.2), but would need to be matched for sensory and hedonic characteristics, such as sweetness and pleasantness. The beverages satiating effects could be measured using a similar preload methodology as the one in paper five, to generate some idea as to how participant's satiety responses vary with the different energy levels. Including a no-preload condition would give a baseline measure of each participant's general intake that could be used to determine whether a particular beverage condition promoted satiety or overconsumption. Because the energy manipulation would be covert, the potential impact of learning after repeated consumption of the similar beverages would need to be carefully considered in order to properly interpret the findings.

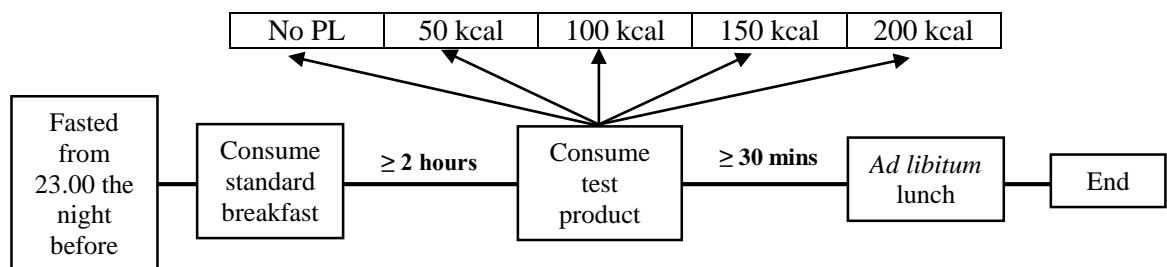


Figure 7.2 Schematic summary of an example study protocol for testing the interaction between the beverages energy content and satiety-relevant context of consumption. These beverages could be consumed in one of several possible combinations of cognitive and sensory contexts, such as: thin vs. thick; OR “drink” vs. “Snack”; OR thin “drink” vs. thin “snack” vs. thick “drink” vs. thick “snack”.

7.5 Final conclusion

The evidence presented in this thesis suggests that the satiating power of a caloric beverage can be influenced by subtle satiety-relevant cognitive and sensory cues. Encouraging the public and food industry to consume caloric beverages in the context of a snack could improve the impact of these nutrients on energy intake regulation, and new beverages could be designed to ensure their sensory characteristics are predictive of the energy they contain. Further research is needed to characterise the physiological and psychological mechanisms behind these effects and to determine the extent to which beverages optimised for satiety might promote improved energy intake regulation and weight management in the real-world.

8. References

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